ACT Government
Transport Canberra and City Services

FREEDOM OF INFORMATION COVERSHEET

The following information is provided pursuant to section 28 of the *Freedom of Information Act 2016*.

FOI reference: TCCSFOI 2019-091 Parts 1&2

Information to be published	Status
1. Access application	Published
2. Decision notice and schedule	Published
3. Documents	Published
4. Additional information identified	No
5. Fees	n/a
6. Processing time (in working days)	45 days
7. Decision made by Ombudsman	n/a
8. Additional information identified by Ombudsman	n/a
9. Decision made by ACAT	n/a
10. Additional information identified by ACAT	n/a

Freedom of Information – Access Application Form

ACT Government
Transport Canberra and City Services

PRIVACY NOTICE

The personal information you supply on this form will only be used for the purpose of processing your request. Your application must include an email or postal address to which the respondent can send notices under the Act. If all or some of this information is not collected, Transport Canberra and City Services may not be able to communicate with you, inhibiting their obligations under the Act. This could mean the request cannot be dealt with. Your personal information will not be disclosed to a third party without your consent unless statutory obligations require otherwise.

The Transport Canberra and City Services Privacy Policy contains information on how you can access or seek to correct any of your personal information that is held by the Transport Canberra and City Services, as well as the process for lodging a complaint about an alleged breach of the *Information Privacy Act 2014*. The Privacy Policy can be found on the Transport Canberra and City Services website at www.tccs.act.gov.au.

Applicant details	
I wish to make an access application to Transport Canberra and City Services under the *Freedom of Information Act 2016*.	
Name	[redacted]
Address (where notices relating to this request can be sent – either postal or electronic)	
Telephone Contact (Business Hours)	
Telephone Contact (Mobile)	[redacted]
Email Contact	[redacted]

What documents are you requesting under the Act?

- Documents relating to the planning, implementation and status of electric vehicles in the ACT Public Transport Fleet. The information provided on Transport ACT's website does not appear to have been updated since prior to planned rollout of more electric busses in late 2018: https://www.transport.act.gov.au/about-us/public-transport-options/bus/about-the-fleet. Fleet information is acknowledged as in the public interest by ACT Transport's aforementioned website.
- Data on public transport usage in the ACT from the MyWay card system. In particular, usage data comparing daily usage of the Light Rail system and the bus routes it replaced would be appreciated. This data being made accessible would allow greater public accountability of major transport infrastructure projects, and improve public evaluation of these systems they use extensively. Opening this data to Canberra's extensive policy and academic community may also generate valuable discussion nd proposals for future transport network development. According to Transport ACT, this data is already depersonalised and used in planning, so should be readily accessible: https://www.transport.act.gov.au/tickets-and-myway/using-myway/privacy.

Fee Waiver

- If you wish to apply for a fee waiver, the Act sets out a number of provisions to do so:
  - The information being requested was previously publicly available but no longer is.
  - The information being requested is of special benefit to the public (Ombudsman guidelines see Section 66).
  - The applicant is a concession card holder and demonstrates a material connection with the information requested (concession cards include a current health care or pensioner card issued under the Social Security Act 1991; a current pensioner concession card issued in relation to a pension under the Veterans' Entitlements Act 1986 or the Military Rehabilitation and Compensation Act 2004; a current gold card; or a card prescribed by regulation).
  - The applicant is a not-for-profit organisation and the application relates to the activities or purposes of the organisation.
  - The applicant is a member of the Legislative Assembly.

Transport Canberra and City Services must waive any fees for providing information if the information was not publicly available and the agency makes the information publicly available before or within 3 working days after giving it to the applicant.

Fee waiver application (fill in if applicable. Otherwise leave blank)

☐ I would like to apply for a fee waiver because (state reason/s from the list above).

[provide details and evidence of how this reason applies]

I would like	a copy of these documents sent to the above address **OR** to inspect these document

APPLICANTS SIGNATURE	DATE OF REQUEST
[redacted]	9 September 2019

ACT Government
Transport Canberra and City Services

[redacted]

By Email: [redacted]

Dear [redacted]

Freedom of information request: Reference – 19-091

I refer to your application made under the *Freedom of Information Act 2016* (the FOI Act), and received by Transport Canberra and City Services Directorate (TCCS), on 5 September 2019 in which you sought access to:

1. Documents relating to the planning, implementation and status of electric vehicles in the ACT Public Transport Fleet. The information provided on Transport ACT's website does not appear to have been updated since prior to planned rollout of more electric buses in late 2018.

2. Data on public transport usage in the ACT from the MyWay card system. In particular, usage data comparing daily usage of the Light Rail system and the bus routes it replaced

I am an Information Officer appointed by the Director-General under section 18 of the FOI Act to deal with access applications made under Part 5 of the Act.

A response was due to you on 3 October 2019. Thank you for agreeing to extensions to 7 November 2019 allow time for TCCS to complete your request.

This decision notice relates to part 1 of your request. A separate decision will be made on Part 2 of your request by 7 November 2019.

Decision on access

One document, the Alternative Fuel Bus Trial Assessment - Final Report was identified as falling under the scope of your request.

I have decided to grant access, under section 50 of the Act, to a copy of the Report with deletions applied to information that I consider would be contrary to the public interest to disclose under the test set out in section 17 of the Act.

Statement of Reasons

In reaching my access decision, I have taken the following into account:

Factors favouring disclosure (Schedule 2.1)

- (a)(i) promote open discussion of public affairs and enhance the government's accountability
- (a)(ii) contribute to positive and informed debate on important issues or matters of public interest
- (a)(iv) ensure effective oversight of expenditure of public funds
- (a)(x) contribute to the protection of the environment.

Factors favouring nondisclosure (Schedule 2.2)

- (a)(ii) prejudice the protection of an individual's right to privacy or any other right under the *Human Rights Act 2004*
- (a)(xi) prejudice trade secrets, business affairs or research of an agency or person
- (a)(xiii) prejudice the competitive commercial activities of an agency.

The TCCS Website is updated on issues such as planning, implementation and other information about the ACT Public Transport Fleet. There are currently no alternative fuel vehicles in the bus fleet although a number of electric and hybrid buses were trialled by Transport Canberra as part of the Alternative Fuel Bus trial which concluded in October 2018 with the final report received by Government in February 2019.

The Minister, Mr Chris Steele MLA, released information about the trial results in a media release on 30 September 2019 which can be found online, and I have this attached for your information. A summary of the final report can also be found at https://www.transport.act.gov.au/__data/assets/pdf_file/0008/1427561/Alternative-Fuel-Bus-Trial-Summary-Assessment.pdf.

The final report has not yet been released publicly as it informed the 2019 procurement of new fleet vehicles which is yet to be concluded.

Concurrent with your request, I have been considering a request which specifically seeks the release of the final report of the trial. I have decided to partially release the report and it will be published in the FOI Disclosure log by 8 November 2019 consistent with the FOI Act.

I have decided to release the report to you before publication. You will note information has been redacted which is contrary to the public interest to release being information that could prejudice the business affairs or competitive commercial activities of Transport Canberra.

A small amount of personal information is also removed as not in the public interest to release.

Online publishing – disclosure log

Under section 28 of the Act, TCCS maintains an online record of access applications called a disclosure log. Your original access application and my decision will be published in the TCCS disclosure log from 3 days after the date of this decision. Your personal details and other personal information will not be published.

You may view TCCS' disclosure log at www.tccs.act.gov.au/about-us/freedom_of_information.

Ombudsman review
My decision on your access request is a reviewable decision as identified in Schedule 3 of the FOI Act. You have the right to seek Ombudsman review of this outcome under section 73 of the FOI Act within 20 working days from the day that my decision is published in the TCCS disclosure log, or a longer period allowed by the Ombudsman.

If you wish to request a review of my decision you may write to the Ombudsman at:
The ACT Ombudsman
GPO Box 442
CANBERRA ACT 2601
Via email: ombudsman@ombudsman.gov.au

ACT Civil and Administrative Tribunal (ACAT) review
Under section 84 of the FOI Act, if a decision is made under section 82(1) on an Ombudsman review, you may apply to the ACAT for review of the Ombudsman decision.

Further information may be obtained from the ACAT at:
ACT Civil and Administrative Tribunal
Level 4, 1 Moore Street
GPO Box 370
Canberra City ACT 2601
Telephone: (02) 6207 1740
www.acat.act.gov.au

If you have any queries concerning the directorate's processing of your request, or would like further information, please contact the directorate's FOI Coordinator on 6205 5408 or email tccs.foi@act.gov.au.

Yours sincerely

[redacted]
Cherie Hughes
Information Officer

31 October 2019

FREEDOM OF INFORMATION REQUEST SCHEDULE

Please be aware that under the *Freedom of Information Act 2016*, some of the information provided to you will be released to the public through the ACT Government's Open Access Scheme. The Open Access release status column of the table below indicates what documents are intended for release online through open access.

Personal information or business affairs information will not be made available under this policy. If you think the content of your request would contain such information, please inform the contact officer immediately.

Information about what is published on open access is available online at: https://www.tccs.act.gov.au/about-us/freedom_of_information/disclosure-log

File No	WHAT ARE THE PARAMETERS OF THE REQUEST
FOI – 19-091 (Part 1)	**Electric Buses and the ACT government public bus fleet**

Pages	Description	Status	Reason for non-release or deferral
1-76	Alternative Fuel bus trial Assessment	Partial release	Schedule 2, 2.2 (a)(ii) - Prejudice the protection of an individual's right to privacy or any other right under the *Human rights Act 2004* (a)(xi) prejudice trade secrets, business affairs or research of an agency or person (a)(xiii) prejudice the competitive commercial activities of an agency

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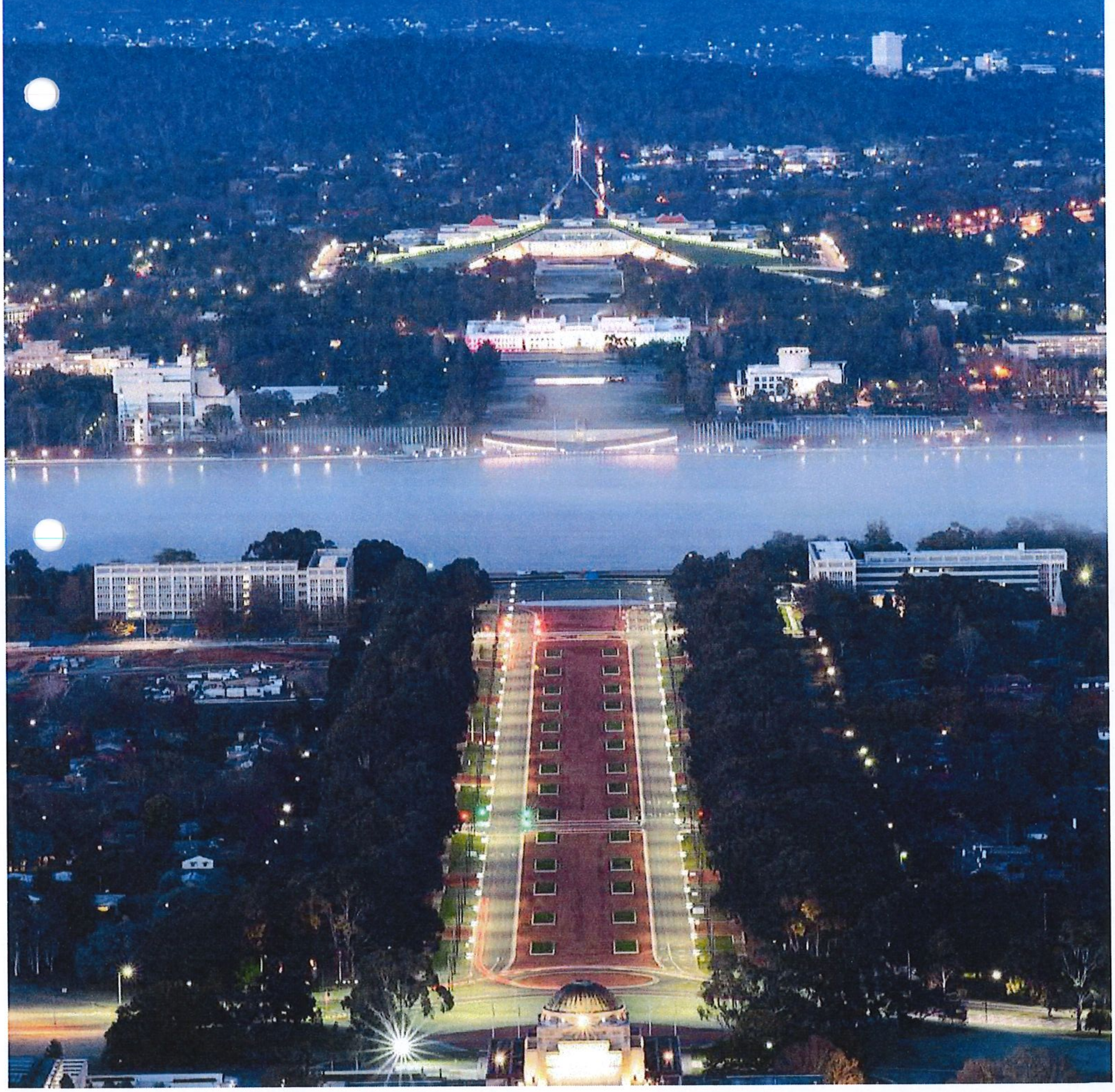
Transport Canberra and City Services
13-Feb-2019

Alternative Fuel Bus Trial Assessment

Final Report



Alternative Fuel Bus Trial Assessment

Final Report

Client: Transport Canberra and City Services

ABN: 37 307 569 373

Prepared by

AECOM Australia Pty Ltd
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13-Feb-2019

Job No.: 6053 5153

AECOM in Australia and New Zealand is certified to ISO9001, ISO14001 AS/NZS4801 and OHSAS18001.

Quality Information

Document Alternative Fuel Bus Trial Assessment

Ref 6053 5153

Date 13-Feb-2019

Prepared by [redacted]

Reviewed by [redacted]

Revision History

Rev	Revision Date	Details	Authorised	
			Name/Position	Signature
0	13-Dec-2018	Draft	[redacted] Principal Engineer	
1	8-Feb-2019	Final Draft	[redacted] Principal Engineer	
2	13-Feb-2019	Final	[redacted] Principal Engineer	[redacted]

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Executive Summary

The ACT's transition to zero emissions vehicles action plan 2018-21 outlines the actions to be implemented to support the rapid uptake of zero emissions vehicles in the ACT as part of the broader plan to ensure Canberra grows into a highly sustainable and liveable city. To help understand the feasibility of transitioning to a zero-emissions bus fleet, based on the current market and technology ability, Transport Canberra has conducted a 12-month trial of buses with alternative fuel use on the ACTION bus network. The results of this trial will provide information on issues to consider in making the transition to a zero-emissions bus fleet.

The trial was primarily focussed on available zero emission technology which at this time in Australia is battery electric buses. A Hybrid diesel /electric bus was also included in the trial to test this technology with battery electric buses and diesel control buses chosen for the trial. While electric buses operate in large numbers in other countries Australia has different, and often stricter, heavy vehicle regulations meaning that at the time of this study there was no suitable mass "off the shelf" product.

The trial commenced in October 2017 with three Scania Euro VI diesel buses, a Volvo Hybrid diesel/ electric (Euro V) bus and one Carbridge Toro battery electric bus. An additional electric bus was added to the trial in March 2018.

This report documents an assessment of the operational, environmental and economic benefits of a future move to electric or hybrid bus technology for additional or replacement fleet purchases. This assessment used information from a range of sources, including:

1. Independent performance testing of buses used for the trial
2. On-board operational data from data loggers installed in the trial buses
3. Driver and passenger surveys.

A summary comparison of key criteria analysed in this this assessment is shown in Table 1. Diesel buses generally perform best in relation to daily operation and financial cost, while electric buses perform best in relation to environmental emissions and energy efficiency. The performance of Hybrid buses generally falls between the diesel and electric bus for all criteria.

Table 1 Summary comparison

Criterion		Diesel Euro VI	Electric	Hybrid Euro V
Operational	Passenger capacity	68 (48 seated)	49 – 55 (35 seated)	68 (44 seated)
	Fuel energy efficiency	938.4 GJ/year	179.6 GJ/year	686.6 GJ/year
	Unscheduled missed peaks	0.8% peaks/bus	35.7% peaks/bus	14.2% peaks/bus
	Range	810 km	450 km	760 km
Environment	GHG (CO_2) emissions	62.7 t/year	1.6 t/year	51.1 t/year
	PM10 emissions	4.9 kg/year	4.6 kg/year	7.1 kg/year
	NO_x emissions	28.6 kg/year	0 kg/year	41.5 kg/year
Economic	Capital cost[3]	[redacted]	[redacted]	[redacted]
	Whole of life cost (financial)	$418,280	$545,665	$597,190
	Whole of life cost (economic)	$1,002,361	$727,055	$1,089,463

Note: 1.Cells highlighted in green show the bus type with the best result for each criterion.
2. Financial cost includes all monetary costs, while economic costs includes monetary and environmental externalities.
3. Capital cost excludes ticketing systems, radio systems, commissioning expenses and other associated costs.

Overall, based on the total monthly greenhouse gas emissions for each bus type, switching from a diesel bus to a hybrid or electric bus would emit less total greenhouse gas emissions (GHG) into the atmosphere and would contribute towards the targets in the *Climate Change and Greenhouse Gas Reduction Act 2010* and the ACT's Climate Action Plan.

Key strengths of each of the buses are:

- Diesel – passenger capacity, reliability (unscheduled missed peaks), capital cost and whole of life financial cost
- Electric – fuel energy efficiency, all emissions (GHG, NO_x and PM10) and whole of life economic cost
- Hybrid - passenger capacity and whole of life economic cost.

Key weaknesses are:

- Diesel - fuel energy efficiency, all emissions (GHG, PM10 and NO_x) and whole of life economic cost
- Electric – passenger capacity, reliability (unscheduled missed peaks), capital cost and whole of life financial cost
- Hybrid – fuel energy efficiency, reliability (unscheduled missed peaks), GHG and NO_x emissions, capital cost and whole of life financial cost.

Driver surveys showed a preference for diesel buses rather than electric or hybrid buses. This is because the diesel buses are considered more reliable, quieter and easier to drive, having better acceleration and braking. Acceleration was highlighted as a weakness of hybrid buses during performance tests, but braking of all buses was similar and considered satisfactory.

Feedback about the electric bus was varied where some drivers felt that the buses were smooth and quiet to drive while others said there was a constant "whining" noise and the drive was rough. Other commentary from drivers about the electric bus was uncertainty regarding their reliability, they were slow to get up to speed and braking could be improved especially when coming into a bus stop. However, speed and braking was not highlighted as a weakness during performance tests.

The consensus of drivers about the hybrid bus was that it was not a pleasant bus to drive. Commentary about the bus was that it was slow through gear changes and was rough to drive. Slow acceleration was also concern and was considered dangerous especially when accelerating from standing.

Passenger surveys on electric and hybrid buses indicated that the performance of these buses in relation to noise, smell and smoothness of travel was satisfactory. The responses were more positive for the electric buses than the hybrid buses, aligning with driver preferences.

The main issues with the electric bus are passenger capacity, cost and reliability. These are likely to be addressed in future. The rate of uptake of electric buses will depend on new or alternative technology which results in vehicles with:

- Lower axle weight with lighter batteries
- Increased seating and overall passenger carrying capacity
- Lower capital costs.

During the trial a major factor limiting the operation of electric buses was their exceedance of legal weight restrictions under the Road Transport (Mass, Dimensions and Loading) Regulation 2010 at the time of their introduction. This resulted in the electric buses being unable to operate for seven weeks or more whilst Transport Canberra obtained a temporary permit for them to operate at 18t in the ACT. Since that time the Mass Dimension and Loading Regulation has been amended to allow operation of two-axle rigid buses to 18t fully laden. The additional weight of an electric bus due to the size battery required to provide a reasonable operating range, creates an issue with their ability to carry the same number of passengers as a comparable diesel bus. This is a potential obstacle for their future use and integration with existing bus operations, but may be overcome by future technological improvements.

Capital costs for electric buses will come down in future. This will occur as demand for these buses increase and more are manufactured.

In terms of operational reliability, the diesel buses performed much better than the electric or hybrid buses, with fewer unscheduled breakdowns for all months of the trial. The electric buses proved to be the most unreliable of the three trial bus types during the trial. They were off the road more than the other buses, not just because of the weight issue but also missed peak services due to unscheduled breakdowns and servicing requirements. The key issues were related to brake and suspension issues; not due to battery system performance (other than weight), but was due to other build quality issues. Better build quality and more local supplier familiarity with the electric vehicle and spare parts could reduce downtime and improve reliability in future.

Transport Canberra should regularly review the technology, specifications and capability of electric buses, with a view to potentially introducing these buses into the Canberra fleet in future. This could occur within two to three years, depending on technological advances and funding and demand for manufacturing larger quantities of electric buses.

1.0 Introduction

Transport Canberra conducted a 12 month trial of electric buses to better understand the operational, environmental and economic performance of electric bus technologies relative to conventional diesel technologies. For the purposes of the trial and because of the eventual transition of the bus fleet to zero emission buses by 2045 mandated by current ACT Government policies, the trial was primarily focussed on available zero emission technology which at this time in Australia is battery electric buses. The inclusion of a Hybrid diesel /electric bus for the trial was to make use of an opportunity to test such technology directly alongside the battery electric product and in comparison with the diesel control buses chosen for the trial. The trial was designed to provide a clear understanding of the performance of electric bus technologies relative to hybrid diesel/electric and conventional diesel technologies.

The primary objective of this project is to assess the potential benefits of introducing electric or hybrid bus technology to replace diesel buses. Specifically, it seeks to:

- Assess the operational performance of electric buses and hybrid buses compared to conventional diesel buses.
- Quantify the potential environmental benefits that may be derived from substituting electric bus or hybrid bus technology for contemporary diesel engine technology
- Quantify the potential economic benefit of investing in electric bus technology compared to hybrid bus or diesel bus technology

The trial enabled the collection of real world data to quantify these benefits. It was conducted using a sample of diesel, electric and hybrid diesel-electric buses, commencing in October 2017 and ending in October 2018. This report documents the data collection, analyses and findings of the trial and includes an assessment of the operational, environmental and economic benefits of a future move to electric or hybrid bus technology for additional or replacement fleet purchases.

2.0 Trial Process

2.1 Introduction

The trial spanned more than 12 months, starting in mid-October 2017 and finishing at the end of October 2018. It utilised three Scania Euro VI diesel buses as control buses (BUS639, BUS640 and BUS641), a Volvo Hybrid diesel electric (Euro V) bus (BUS712) and two Carbridge Toro battery electric buses (BUS710 and BUS711). These buses were located in the Tuggeranong Bus Depot and operated from there within the Transport Canberra bus network each day of operation.

New buses were used in the trial, recently delivered under the Transport Canberra bus replacement program. The trial commenced in October 2017 with only one electric bus (BUS710).

An additional electric bus (BUS711) was ordered to take part in the trial for delivery in December 2017 however delivery of this bus was delayed and eventually the bus arrived in March 2018.

On arrival the bus was found to be overweight and subsequent investigations also found the first bus to be overweight. Subsequently, both electric buses were unable to operate whilst a solution was sought to enable them to return to service. Transport Canberra sought exemptions from the Mass and dimensions regulations for these buses to enable them to operate at up to 18t fully laden. The first electric bus (BUS710) was returned to service on May 9, 2018 once a permit to operate at 18t was provided by the National Heavy Vehicle Regulator (NHVR). The second bus (bus711) was also granted an exemption at the same time, however it did not enter service until mid-August 2018 due to other safety issues.

Transport Canberra called for bus drivers volunteers to be involved in the trial. A pool of 30 volunteer drivers were selected by Transport Canberra in September 2017. The volunteer drivers were trained in the specifics of operating hybrid and electric buses where these varied from diesel bus characteristics they were used to. During the trial the drivers operated a mix of the diesel buses, hybrid and electric buses to ensure a level of consistency of operator quality during the trial period. It was not possible to control the experiment by driver.

During the trial the buses driven were exposed to different and varied duty cycles that included a mix of peak, off peak, suburban and school services according to the shift they operated each day. The buses themselves also have different characteristics (e.g. passenger capacity) which influenced the duty cycle they were able to operate. All of the work performed, the routes, hours in service, km travelled and passengers carried by the various buses in the trial were recorded and analysed for the purposes of the trial.

Information was collected during the commissioning of the hybrid and electric buses, through benchmark performance tests. In addition, there were four forms of data collection during the trial:

1. On-board operational data
2. MyWay bus and passenger data
3. Workshop maintenance and incidents data
4. Driver and passenger surveys.

2.2 Benchmark Performance Tests

Standard benchmark acceptance tests were conducted for each of the trial buses. A summary comparison of the performance specifications of each of the buses is given in Appendix A.

All buses passed each of the acceptance tests. The Volvo Hybrid was given a conditional pass for heating, subject to the heating control being able to be adjusted to 22 C. (This was rectified by Volvo almost immediately.)

The diesel bus performed best against most of the performance criteria. More details of the outcomes of these tests are given in Section 4.2.2.

2.3 On-board Operational Data

Data loggers supplied by Mix Telematics were installed on all of the diesel and hybrid trial buses during the trial, but Carbridge chose to also install their ViriCiti data logger on the electric bus. Both data logging devices provided similar data to allow a sound comparison of performance against a range of criteria. The Telematics data became available on 16 October 2017, so the first full month of reporting was in November 2017

Telematics data recorded was accessible via the Telematics or Viriciti websites. It can be exported to CSV or EXCEL format, for subsequent analysis prior to entry into the monthly dashboard.

The Mix Telematics data from both sources was available to be exported in various forms uniquely identifiable by the date and bus number for each trip.

Key Telematics data available for analysis included:

- Date
- Time
- Vehicle - bus number
- Standing Time %
- Idling Time %
- Distance Driven (km)
- Fuel Used (Litres)
- Energy Used kW/h
- Fuel Consumption (L/100km)
- Energy Consumption kW/h/100km
- CO_2 (kg) Estimate
- Avg. Speed (km/h).

For the electric buses, the Viriciti data was able to be exported to CSV or EXCEL for each selected performance parameter used in the analysis. Each parameter was exported in the form of format files, identified by bus number, date and time.

The additional Viriciti data available for analysis included:

- Average speed
- Energy used per day (kWh)
- Energy charged per day (kWh)
- Current State of charge (%)
- Estimated remaining range (km)

Both data logging systems allowed real-time monitoring of the trial buses.

2.4 MyWay Data

Transport Canberra's MyWay Ticketing System can produce reports on passenger movements. The system can produce data by bus stop ID, route number, bus number and time of day. Passenger boarding and stop arrival time is recorded at each stop and can be compared with scheduled arrival time. Passenger boardings are recorded for all passengers but alighting is only recorded for passengers who have a MyWay card. The data was provided by Transport Canberra in EXCEL format.

Travel distances, times and speeds can be obtained from the MyWay system. These formed an important element in the operational, environmental and economic analyses, enabling metrics to be reported in per passenger km as well as km.

Key MyWay data used in the production of monthly reports and economic analyses included:

- Date
- Vehicle - bus number
- Passengers on board
- Revenue
- Licenced capacity
- Failure to complete service.

The MyWay data is available by route and stop sequence, so it was averaged by route.

2.5 Workshop Data

Workshop data largely relies on information provided via the TIMS (Transport Integrated Management System) workshop management tool. This includes cost and incident data. Descriptions and costs of repairs provided through TIMS include all vehicle operations, servicing and maintenance data for each of the vehicles in the trial.

TIMS contains a database of vehicle service history, breakdowns, incidents, warranty reports and parts use. The cost / monitoring system for the Scania buses is well established in TIMS. There are many TIMS reports and these can be downloaded in PDF or EXCEL – a sample extract from a service report is shown in Figure 1. Lifetime reports can be obtained for any bus, as well as average costs, per month, per year, etc.

Veh#	Date	W/O#	Fault#	Ext Cost	Item	Description	Notes	Service	Odometer	Fault Type	Fault Subtype
586	27/11/2015	0		$ -		Imported Service History	Imported Service History	A	524		
586	27/11/2015	0		$ -		Imported Service History	Imported Service History	B	524		
586	8/12/2015	252205	209016	$ 178 50		Accident Damage N/Side Damage in front of rear door look	Tidy up accident damage.	ACC	3529	ACC	ACC3
586	8/12/2015	252205	209015	$ 5.44	15490	AMBER REFLECTOR AGORALINE/SCANIA STICK ON		BOD	3529	BODY	BODY2
586	18/12/2015	252933	210239	$ 59 50		Body/Seats/Windows Mirrors OS mirror to high.	Adjusted mirror height.	BOD	3860	BODY	BODY5
586	17/12/2015	252856	210094	$ 119 00		Body/Seats/Windows Drivers Cabin Area water comes into dr	Sealed around Ariel base	BOD	3860	BODY	BODY7

Figure 1 Sample service report from TIMS

Diesel fuel cost ($/litre for each fuel load delivered) was average weekly or monthly fuel pricing was provided by Transport Canberra. Each diesel and hybrid bus were able to electronically record fuel used using the on-board computer. This was verified using data from Transequel, Transport Canberra's fuel monitoring system.

The service, breakdown, incident and warranty reports rely on accurate field information and entry into TIMS. Sometimes the field information is lacking in detail and km may be inaccurate or occasionally missing and there are a large range of service and fault descriptions. However, all care was taken to accurately record maintenance and servicing events for the trial vehicles during the trial.

Incidents include vehicle breakdowns, accidents, passenger incident or service cancellations. These incidents can affect the trial and the basis of comparisons. The nature of the vehicle breakdowns is also important, especially if technology-related.

Charging equipment was installed at Tuggeranong Depot to charge the 2 electric buses. Separate charging data was available for each bus. Systems on board the electric buses also recorded energy used, regenerated and remaining. Maintenance and servicing data for the electric and hybrid buses was provided independently of TIMS as this was conducted by Carbridge and Volvo respectively.

2.6 Driver and Passenger Surveys

Qualitative driver and passenger feedback on use of trial buses (diesel, electric and hybrid) was obtained by Transport Canberra's marketing and communications team. For drivers and passengers, comfort, drivability and reliability will be important factors.

Cost, time, comfort, safety and feelings of wellbeing are all key aspects affecting the uptake of public transport. Customer feedback is important for assessing the satisfaction and attractiveness of electric buses relative to diesel buses. Factors considered as part of this survey to differentiate between diesel, electric and hybrid buses were interior temperature, ride comfort, smell, noise and smoothness of ride, as well as overall passenger preference for diesel or electric bus.

2.7 Limitations with Trial

Failure to ensure operational similarity could lead to concerns that any differences in performance could reasonably be attributed to differences in vehicle operation (e.g. drivers, routes), as opposed to differences in combustion technology. The main limitations with the trial were:

- The number of buses used in the trial – 3 diesels, 1 hybrid and 1 electric[1]
- Capacity and weight limitations with the electric buses
- Buses servicing different routes resulting in different kilometres travelled and passengers carried
- A different on-board data collection system for the electric buses
- A small number of driver and passenger surveys – 8 drivers, 14 hybrid passengers and 59 electric bus passengers.

A number of these limitations are offset by the length of the trial (12 months).

[1] A second electric bus was introduced late in the trial, but it travelled limited kilometres.

3.0 Data Collection and Analysis

3.1 Data Collection

The data needed for this trial had to enable the monthly reporting of operational performance and service delivery, as well as the final economic and environmental assessment. There are different needs for each of these elements of the assessment.

A summary of overall data collection for the project and its purpose is provided in Table 2. This splits data into several levels:

1. Key assessment criteria
2. Key assessment parameters
3. Data collection
4. Reporting.

Table 2 Data Collection Summary

Key Assessment Criteria		Key Assessment Parameters	Data Collection	Reporting
Commissioning effort	Ease of commissioning Where there is a variance from the norm	Description of infrastructure and facility requirements to convert from diesel to electric or hybrid fleet	• Qualitative only, experience-based and informed by interviews with Transport Canberra and bus manufacturers	• Final Report – include details on benchmark testing for all buses
	Mechanic and driver training	Description of training requirements and workforce impact to convert from diesel to electric or hybrid fleet	• Qualitative only, experience-based and informed by interviews with Transport Canberra and bus manufacturers	• Final Report – include in interim report once complete
Operational performance	Vehicle driveability	Driver responses to questions regarding: cabin comfort, road safety, manoeuvrability, power, fuel range anxiety	• Questionnaire surveys of drivers • Fortnightly driver meetings • Additional feedback	• Comments in months where questionaries submitted • Summary and analysis in final Report
	Vehicle performance	Average speed, instantaneous velocity; acceleration / deceleration; idling, coasting, speeding, harsh brake applications	• On-board data logger • From MyWay data	• Comments in monthly reports

	Key Assessment Criteria	Key Assessment Parameters	Data Collection	Reporting
Operational performance (cont'd)	Vehicle reliability	Unscheduled lost time	• Questionnaire surveys of drivers • Fortnightly driver & workshop staff meetings • TIMS / Depot staff	• Monthly hours of scheduled maintenance • Monthly hours of unscheduled maintenance / breakdowns • Down time from other incidents such as crashes or uncontrollable external factors. • Comments / perception from workshop staff and drivers
	Operating costs	Fuel use efficiency & cost, maintenance costs	• TIMS • On-board data logger • Electric charging (Depot staff)	• Monthly reporting for: – Fuel use – Cost per unit of fuel • Monthly maintenance costs
Service delivery	Passenger experience	Passenger responses to questions regarding: cabin comfort, reliability, noise, smell, preference	• Questionnaire surveys of passengers • Survey group meetings	• Comments in months where questionaries submitted • Summary and analysis in final Report
	Service delivery	% scheduled services delivered/completed	• From Depot staff	• Monthly indicator • Incidents of bus full trigger reported on
	Passenger capacity	Maximum capacity & passenger loading to capacity	• Benchmark tests • From MyWay data	• Monthly
Environment	Air quality	Particulate matter emission rates	• Calculated from average bus travel (in km)	• Monthly
	GHG emissions	GHG emission rates (primary, secondary)	• Calculated from fuel consumption and electric charging data	• Monthly
	Noise	Passenger comfort	• Passenger surveys • Public feedback • Bus manufacturer statements	• Comments in months where surveys received / quarterly • Summary and analysis in final Report

	Key Assessment Criteria	Key Assessment Parameters	Data Collection	Reporting
Economic	Vehicle-life costs	Capital costs – bus fleet, infrastructure	• Transport Canberra and bus manufacturer interviews • Research	• Summary and analysis midyear with review in final Report
		Fuel costs and efficiency - measured electricity/diesel use and route distance	• TIMS • On-board data logger	• Monthly
		Other variable / operational costs	• TIMS • Bus manufacturer interviews	• As required
		Depreciation and residual asset value	• Calculated	• Summary and analysis midyear with review in final Report
	Revenue	Induced passenger demand	• MyWay data • Research	• Demand not likely to be determined by type of bus – capacity changed captured through per passenger km travelled analysis and normalised access all bus types
	Emissions	Savings in noise and emissions costs	• Calculated	• Monthly
	Commissioning	Mechanic and driver training costs	• Transport Canberra interview	• Summary and analysis midyear with review in final Report
Social	Noise & air quality	Improved amenity, contribution to city liveability	• Public feedback • Passenger & driver surveys	• Comments in months where surveys received • Summary and analysis in final Report
	Workforce impacts	Staff training and comfort	• Questionnaire surveys of drivers	• Comments in months where surveys received • Summary and analysis in final Report

Note: Some of the commissioning, operational performance criteria (e.g. fuel use, operating costs) and environment criteria are also important in assessing economic performance.

3.2 Assessment Elements

3.2.1 Commissioning Effort

In relation to the trial, information on infrastructure and facility requirements, driver training and workforce impacts are important for the economic assessment and social impacts. This data will be a mix of qualitative and quantitative information, informed by information provided by Transport Canberra.

3.2.2 Operational Performance and Service Delivery

Operational performance and service delivery relies on the data collected from the on-board data loggers, TIMS and driver/passenger surveys. A summary of operational performance and service delivery data elements is given in Table 3.

Table 3 Operational performance and service delivery data

Parameter	Measure	Availability
Average speed	km/h	For every trial bus route segment
Fuel/energy usage	kL or GJ	For every trial bus per bus trip
Fuel costs	$	For every trial bus per bus trip
Maintenance costs	$	For every trial bus per week or month
Distance travelled	km	For every trial bus trip
Days in service	Days	For every trial bus per week or month
Operating time	h	For every trial bus per week or month
Idling time	% engine running time	For every trial bus trip
Coasting	% of distance	For every trial bus trip
Speeding	% engine running time	For every trial bus trip
Passenger loadings	pass/km	For every trial bus route segment
Overall reliability	Qualitative	Driver surveys, breakdown and maintenance data
Service delivery	% scheduled services delivered	For every trial bus route segment
Driver comfort	Qualitative	Driver surveys
Driver control	Qualitative	Driver surveys
Unscheduled lost time	% operating time	Lost time that can be attributed to the technology
Noise	Qualitative	Passenger surveys
Smell	Qualitative	Passenger surveys
Passenger comfort	Qualitative	Passenger surveys

Note: Data can be amalgamated and averaged to form running weekly or monthly parameter estimates for each bus type

3.2.3 Environmental Assessment

To undertake the environmental assessment the following data was used:

- Fuel type and quantity (kL or GJ). Emissions were inferred from fuel type and not monitored through end-of-pipe measurement.
- Distance travelled to infer PM10 emissions.
- Battery charging - The time of day for battery charging (peak/off-peak electricity pricing) can also affect total costs.

Scope 1 or direct GHG emissions will be calculated from the quantity of fuel used by type (in kL or GJ), using the energy and emission factors specified in the '*National Greenhouse Accounts Factors*' publication (Australian Government, August 2016). The formula for Scope 1 emissions is as follows:

$E_{ij} = Q_i \times EC_i \times EF_{ijoxec}$

where:

E_{ij} is the emissions of gas type j, carbon dioxide, methane or nitrous oxide, from fuel type i (CO_2-e kg)

Q_i is the quantity of fuel type i (kL or GJ) combusted for transport energy purposes

EC_i is the energy content factor of fuel type i (GJ per kL) used for transport energy purposes (refer Table 4, Australian Government 2016)

If Q_i is measured in gigajoules, then EC_i is 1

EF_{ijoxec} is the emission factor for each gas type j (which includes the effect of an oxidation factor) for fuel type i (kg CO_2-e per GJ) used for transport energy purposes (refer Table 4, Australian Government 2016 for diesel and; Table 2, Department of Environment and Energy 2018 for electricity).

GHG emissions from secondary sources (Scope 2 GHG emissions) such as electricity and power use is calculated on the basis of electricity used for battery recharge purposes (in kWh).

The formula for calculating Scope 2 GHG emissions is as follows:

$Y = Q \times EF$

where:

Y is the Scope 2 emissions measured in CO_2-e kg

Q is the quantity of electricity purchased (kW-h)

EF is the Scope 2 emission factor, for the State, Territory or electricity grid in which the consumption occurs (kg CO_2-e per kW-h). The emission factor is highly dependent on the energy mix being used. As the ACT Government move towards their 2020 100% renewable energy target the emissions associated with electricity generation will decrease. This will lead to a decline in the emission factor that should be used[2].

PM10 is the major air pollutant with strong implications for coronary diseases. This can be calculated with updated values from the publication *'Valuation of Pollutants Emitted by Road transport into the Australian Atmosphere'* (Beer, 2002) – in $ per pollutant. PM10 emissions will be calculated from distance travelled (in g/km).

A summary of the Scope 1 and 2 data are given in Table 4 and Table 5, respectively. Other data of interest to the emissions analysis is summarised in Table 3.

[2] https://www.environment.act.gov.au/cc/acts-greenhouse-gas-emissions/measuring-act-electricity-emissions

Table 4 Scope 1 GHG Emissions data needs

Parameter	Measure	Comment
Fuel consumed	kL	For each relevant trial bus per month
Route length	km	For every trial bus trip
Route duration	h	For every trial bus trip

Note: Average travel speed can be calculated from route length and duration

Table 5 Scope 2 GHG Emissions data needs

Parameter	Measure	Comment
Electricity consumed	GJ	For each relevant trial bus per month
Workshop electricity	kWh	For each trial bus per month
Battery charge	kWh	For every trial bus per month

Note: It is difficult to separately identify workshop electricity used in servicing individual buses.

Fuel and electricity consumption are considered scope 1 and scope 2 emissions respectively due to the location at which greenhouse emissions are generated. Fuel consumption emits greenhouse gases at the vehicle's location while the emissions for electricity generation occur at the power plant.

3.2.4 Economic Assessment

The economic assessment framework is illustrated in Figure 2.

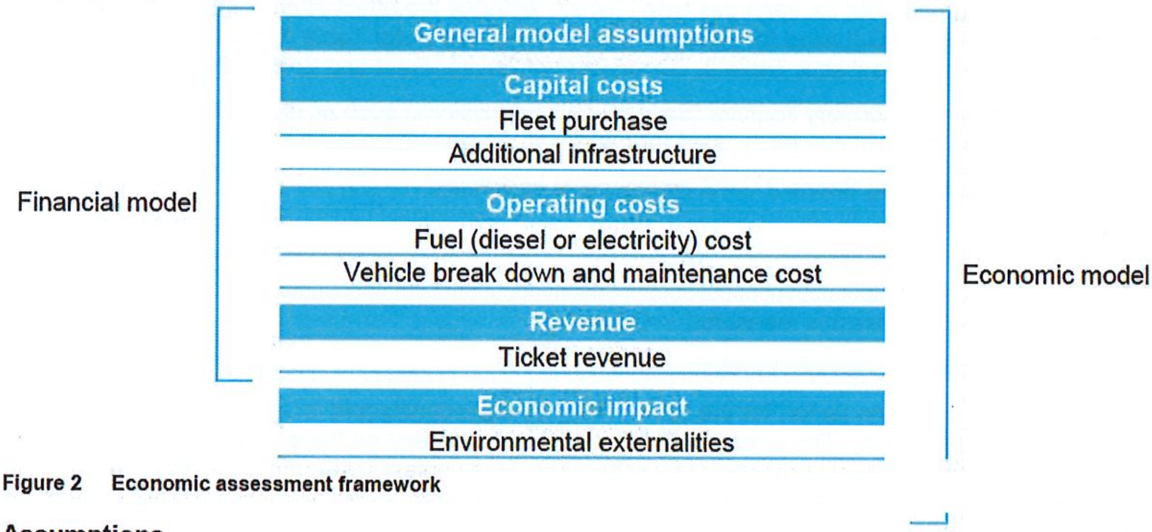

Figure 2 Economic assessment framework

Assumptions

Aligned with the assessment framework illustrated above, assumptions that underpin the model can be categorised into one of five categories:

1. General model assumptions
2. Capital cost assumptions
3. Operating cost assumptions
4. Revenue assumptions
5. Economic impact assumptions.

The assumptions within these categories, which are detailed in Table 6 through to Table 10, are based on industry knowledge and standards, supplied cost data and data recorded during the trial. All cash flows in this report exclude GST.

Table 6 General model assumptions

Assumption	Explanation
Model start year	The economic model commences at the end of the 2018-19 financial year
Appraisal period	A 20-year appraisal period was applied due to the life of the electric bus
Discount rate	A discount rate of 7% is applied to all cost and revenue items

Table 7 Capital cost assumptions

Assumption	Explanation
Bus purchase price Data source: TCCS	**Diesel:** [redacted] **Electric:** [redacted] **Hybrid:** [redacted] All bus purchase prices have been adjusted to reflect estimated 2018-19 costs. The inflation rate applied is 2% p.a.
Supporting infrastructure Data source: installation costs provided by TCCS Bowser/charging station to bus ratio estimated by AECOM	Stabling and maintenance facilities have been excluded from the analysis. The only supporting infrastructure cost is assumed to be fuel bowsers for the diesel vehicles and charging stations for the electric and hybrid vehicles. **Diesel:** For the diesel and hybrid buses, [redacted] **Electric:** For the electric buses, [redacted]

Note: Capital cost excludes ticketing systems, radio systems, commissioning expenses and other associated costs.

Table 8 Operating cost assumptions

Assumption	Explanation
Vehicle kilometres travelled (VKT) Data source: Telematics monthly trip report	The vehicle kilometres travelled for each bus were calculated on a monthly basis and then annualised. **Diesel:** Diesel buses travelled an average of 6,342 km per month, which provides an annual VKT of **76,108 km** (accounting for rounding). **Electric:** Electric Bus 710 travelled an average of 3,271km per month, which provides an annual VKT of **39,256 km** (accounting for rounding). **Hybrid:** The Hybrid bus travelled an average of 2,253km per month, which provides an annual VKT of **27,036** km (accounting for rounding).
Fuel price Data source: Diesel and electricity prices were provided by TCCS	The annual fuel price for each bus type is based on the price for a litre of diesel or kWh electricity, the rate at which the diesel or electricity is consumed and the annual VKT for each bus type. These values are assumed to remain constant throughout the entire appraisal period. It should be noted however that fuel and electricity prices may not be constant and may rise in the future resulting in a higher or lower cost than modelled in this trial.

Assumption	Explanation
	Diesel: Data from September 2017 to January 2018 provides an average diesel price of [redacted] **Electric:** The data provides a varying electricity price based on time of day: • [redacted] [redacted] [redacted]. An agreed usage [redacted]. Energy prices have been quite volatile in recent times. This report is based on electricity prices for 2018, [redacted] **Hybrid** The consumption rate of diesel [redacted]
Service and maintenance costs Data source: TCCS	Actual service and maintenance costs were calculated on a monthly basis, then calculated per VKT and annualised based on predicted annual VKT. **Diesel:** The data provides an average monthly maintenance cost of [redacted] **Electric:** The data provides an average monthly maintenance cost of [redacted] **Hybrid:** The data provides an average monthly maintenance cost of [redacted] Additional maintenance data was provided for all buses in the ACTION fleet, but some of this was under warranty and the nature of many of these costs made it difficult to project these costs over the 20 year life of each bus, so these were not used in the analysis. A sensitivity test of increased service costs has been included to notionally illustrate the impact of greater servicing/maintenance expenditure.

Battery replacement Data source: TCCS	**All bus types:** Standard bus batteries are assumed to be replaced every two years for each bus type at a cost of [redacted] per battery. **Hybrid:** The hybrid vehicle battery in use cos [redacted] per battery and requires replacing every 10 years. This equates to a cost of [redacted]. **Electric:** The electric vehicle batteries in use have an eight-year warranty at 65% capacity. Batteries are, therefore, assumed to be replaced every eight years at [redacted].
Fuel pump Data source: TCCS	**Diesel and hybrid:** A fuel pump is a component of the diesel and hybrid engines only. It is a small cost o [redacted].
Fuel injector Data source: TCCS	**Diesel and hybrid:** A fuel injector is a component of the diesel and hybrid engines only. It is a relatively small cost of [redacted].
Engine transmission Data source: TCCS	**Diesel and hybrid:** The engine transmission of each diesel and hybrid bus requires replacement every one million VKT and, therefore, occurs only once during the appraisal period. Replacement cost is [redacted]
Electric hub motor	**Electric:** The electric bus has two hub motors which are expected to require replacement every $400,000km. [redacted].

Table 9 **Revenue assumptions**

Assumption	Explanation
Ticket revenue Data source: MyWay data	Ticket revenue has been averaged across all bus types as bus type is not expected to influence rider behaviour. The average ticket revenue of all buses during the trial was [redacted]
Bus advertising revenue	Revenue associated with advertising on buses and at bus stations has been excluded from the analysis.
Residual asset value Data source: Bus life expectancy provided by TCCS	The life expectancy of all buses is **20 years**. Given the appraisal period is also 20 years, none of the bus options will have a residual asset value.

Table 10 Economic impact assumptions

Assumption	Explanation
Crash costs	The social impact of crashes (i.e. life) have not been factored into the model
Externalities	**Diesel:** Externalities considered include air pollution, greenhouse gas emissions, noise pollution, water pollution, urban separation and upstream and downstream impacts. These have been accounted for as per guidance in Transport for New South Wales (TfNSW) *Principles and Guidelines: Economic Appraisal of Transport Investments and Initiatives (2016)*. **Electric:** Externalities considered include noise pollution, urban separation and upstream and downstream impacts only. These were accounted for as per guidance in TfNSW *Principles and Guidelines: Economic Appraisal of Transport Investments and Initiatives (2016)*, however, the externality cost for noise was halved due to the comparatively reduced noise of electric buses when compared to diesel buses. Air pollution, greenhouse gas emissions and water pollution were not included as these externality types are not directly produced by electric buses. **Hybrid:** Externalities considered are the same for the diesel bus type; however, the values (with exception to urban separation and upstream and downstream impacts) have been multiplied by a factor of 0.78. This is the ratio of diesel consumed by the hybrid (29L/100km) to average diesel consumption of the diesel buses (37L/100km). Table 11 summarises the environmental externalities (or external costs) used for buses on urban roads. These values have been sourced from: *Principles and Guidelines for Economic Appraisal of Transport Investment - March 2016 (TfNSW), Table 58: Externality unit costs for passenger vehicles and buses.*

Table 11 Environmental externalities

Externality	Unit	Unit cost (March 2016)	Diesel Unit cost (Jun 2019)	Electric Unit cost (Jun 2019)
Air pollution	$/Bus-km	$0.36	$0.38	$-
GHG emission	$/Bus-km	$0.15	$0.16	$-
Noise	$/Bus-km	$0.02	$0.03	$0.01
Water pollution	$/Bus-km	$0.05	$0.06	$-
Nature & landscape	$/Bus-km	$-	$-	$-
Urban separation	$/Bus-km	$0.02	$0.02	$0.02
Upstream and downstream	$/Bus-km	$0.22	$0.23	$0.23

Note: 1. GHG is greenhouse (CO_2) gas emissions

2. Air pollution - includes carbon monoxide (CO), nitrogen oxide (NOx) and hydrocarbon (HC) emissions

3. Water pollution - includes organic waste or persistent toxicants run-off from roads generated from vehicle use: engine oil leakage and disposal, road surface, particulate matter and other air pollutants from exhaust and tyre degradation

4. Nature & landscape – not considered as is assumes no new facilities or impacts of the infrastructure 'footprint', e.g., habitat loss, loss of natural vegetation or reduction in visual amenity as a result of bus technology

5. Urban separation is based on three elements: time loss due to separation for pedestrians, lack of non-motorised transport provision and visual intrusion – assumed the same for all bus technologies

6. Upstream and downstream costs refer to the indirect costs of transport including energy generation, vehicle production and maintenance and infrastructure construction and maintenance.

3.3 Monthly Reports

Monthly reports were produced to provide summary information on the progress of the trial. AECOM developed an interactive dashboard to display the information using the Tableau software. The dashboard outlines the key metrics used in the trial and provided an interactive visual assessment for tracking the progress of the trial. A sample of the main page of the monthly dashboard is shown in Figure 3.

3.3.1 Metrics and Data

A summary of parameters and data sources used to create the monthly dashboard are provided in Table 12. Comments are also provided in relation to the derivation of the parameters.

Fuel costs and emission rates can be expressed as a function of km or passenger-km. The latter measure is preferable as patronage varies significantly between the diesel and electric trial buses.

Figure 3 Dashboard using key metrics

Table 12 Data sources for monthly dashboard

Parameter	Data Sources	Method of Obtaining Data	Comment
Bus number & date	All	All sources	Links data between sources
km travelled	Telematics (depot to depot)	Mix Reports and /or Viriciti website	Determined by using the Mix reports for the hybrid and petrol buses and Viriciti for the electric buses. Both cases use the average on the front of the dashboard.
Passenger km travelled	MyWay Data	Provided periodically by Transport Canberra	Calculated by multiplying passengers by their trip distance.
PM10	Derived from above	As above & formula	Calculated from distance travelled
GHG Scope 1	Telematics (fuel) Depot (electricity consumption)	Mix reports and/or Viriciti website Provided periodically by Transport Canberra	Calculated from fuel consumed by fuel type TIMS can be used as a check of fuel consumed
GHG Scope 2	Depot (electricity consumption)	Provided periodically by Transport Canberra	Calculated from quantity of electricity for battery recharging (in kWh)
Fuel use	Telematics (fuel) Depot (electricity consumption)	Mix reports and /or Viriciti website Provided periodically by Transport Canberra	in kL (fuel) or GJ (electricity consumption)
Reliability	TIMS, depot	Provided periodically by Transport Canberra	Measure as % days in service
Fuel efficiency ($/km)	Depot - $/kl and $/GJ	Calculated from above	Derived from km travelled, fuel use and cost rates ($/kl and $/GJ)
Emission Intensity	Derived from above data	As above & formula	Emissions/km

3.3.2 Data Analysis

Some analysis of the raw data collected during the trial was necessary in order to summarise the data presented in in the Tableau Dashboard, including passenger-km, fuel efficiency, reliability and various emissions (PM10, NOx, GHG-1 and GHG-2). A summary of the analysis and assumptions is given in Appendix C.

4.0 Operational Assessment

4.1 Introduction

The operational assessment considered the following aspects of bus operation:

- Operational capability
- Operational reliability
- Operational capacity
- Operational efficiency
- Integration with current operations.

The operation of the three bus types were compared monthly during the trial period. Weekly and monthly trends were assessed in terms of the distance travelled, passenger-km travelled, reliability and fuel and energy efficiency.

In September 2018, driver and passenger surveys were undertaken to obtain feedback on the operation of the hybrid and electric buses. The driver surveys included questions relating to opinions driving the hybrid and electric buses, compared with diesel buses. The passenger surveys had questions relating to their experience travelling in the hybrid and electric buses.

4.2 Operational Capability

Capability was assessed from benchmark tests in commissioning the buses and during operation. Surveys of drivers also provided important opinions regarding the capability of the various buses during operation.

4.2.1 Commissioning

The tasks involved in establishing electric bus operations for this trial included the following:

- An electric bus supplier had to be identified that had both the capability to support their product as well as supply their product on time.
- Transport Canberra had to obtain buses that met the specifications and get them delivered. Due to weight restrictions it was necessary to obtain a permit to operate these buses.
- Transport Canberra had to obtain, install and operate battery recharge facilities in Tuggeranong Depot where the buses were garaged.
- Benchmark tests were undertaken by Transport Canberra to establish bus capability.
- Drivers had to be trained in the use of the new buses.

The main factor limiting the operation of electric buses was their exceedance of legal weight restrictions under the Road Transport (Mass, Dimensions and Loading) Regulation 2010. This resulted in the electric buses being off the road for seven weeks or more[3] whilst Transport Canberra obtained a temporary permit for them to operate on Canberra roads. It is a major obstacle for their future use and integration with existing buses, but may be overcome by future technological improvements.

[3] When the second electric bus arrived in March 2018 it was found to be overweight. A check of the first electric bus was then undertaken and it was also found to be overweight. The first electric bus stopped operation on 21 March and returned to service on 9 May 2018. The second electric bus did not start operation on Canberra's road system until 16 August 2018 – a substantial delay of 5 months. The prolonged delay was due to a safety issue with the second electric bus that took a long time to resolve.

4.2.2 Benchmark Tests

Standard benchmark acceptance tests have been undertaken for each of the trial buses. A summary comparison of the performance specifications of each of the buses is given in Appendix B.

All buses passed each of the acceptance tests. The Volvo Hybrid was given a conditional pass for heating, subject to the heating control being able to be adjusted to 22 C.

The diesel bus performed best against most of the benchmark test performance criteria. Key strengths of each of the buses are:

- Diesel - internal noise at 50 km/h, passenger capacity and turning circle
- Electric - temperature control (heating & air conditioning) and internal noise when stationary
- Hybrid - temperature control, passenger capacity and external noise in a drive-by.

Key weaknesses in the benchmark tests are:

- Diesel - temperature control and external noise in a drive-by
- Electric - internal noise at 50 km/h, external noise, seating capacity and turning circle
- Hybrid - internal noise at 50 km/h and acceleration.

4.2.3 Driver Surveys

A total of eight driver surveys were completed in September 2018 relating to questions about the hybrid and electric buses. The survey contained four questions, relating what the drivers did and did not like about driving the buses. In addition, drivers were asked about their thoughts on the future introduction of the hybrid and electric technology into the Transport Canberra bus fleet and other general feedback.

Feedback about the electric bus was varied. Some drivers stated that the electric buses were smooth and quiet to drive while others said there was a constant "whining" noise and the drive was rough. Others commented that they were slow to accelerate and braking could be improved especially when coming to a stop.

The general consensus about the hybrid bus was that it was not a good bus to drive. Drivers stated that the bus was slow through gear changes and was rough to drive. Slow acceleration was also a concern and was considered dangerous, especially when accelerating from a stop.

Drivers preferred driving the diesel bus rather than the electric or hybrid bus. The hybrid bus was least desirable and drivers would not recommend them to be introduced into the Transport Canberra bus fleet. However, for the electric bus, drivers would recommend its introduction to the fleet if the technology improved in terms of reliability and acceleration.

4.3 Operational Reliability

Reliability was assessed by the amount of travel undertaken by the different buses and missed peaks. The driver surveys also provided some feedback on bus reliability.

In terms of operational reliability the diesel buses performed much better than the electric or hybrid buses. The electric buses proved to be most unreliable during the trial. They were off the road more than other buses, not just because of the weight issue but also missed peaks due to unscheduled breakdowns. This was not due to battery system performance (other than weight), but was due to other build quality issues.

4.3.1 Driver Surveys

The surveys indicated driver concerns and uncertainty regarding the reliability of electric buses, including available driving range.

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4.3.2 Amount of Travel

The amount of travel provides an indication of operational reliability as it reflects time off the road and unavailable for operation. For months where all buses were operating consistently the differences in travel reflects different route scheduling.

There was a noticeable variation in distance and passenger-km travelled by the trial buses (Figure 4 and Figure 5). The diesel buses consistently travelled the highest kilometres and passenger-km across the months, except in September 2018 and October 2018 where the electric buses showed the highest passengers-km travelled. The hybrid bus generally travelled less distance than the electric bus. The exception was March to May 2018 when the electric buses were taken off the road due to weight restrictions, until an exemption was obtained.

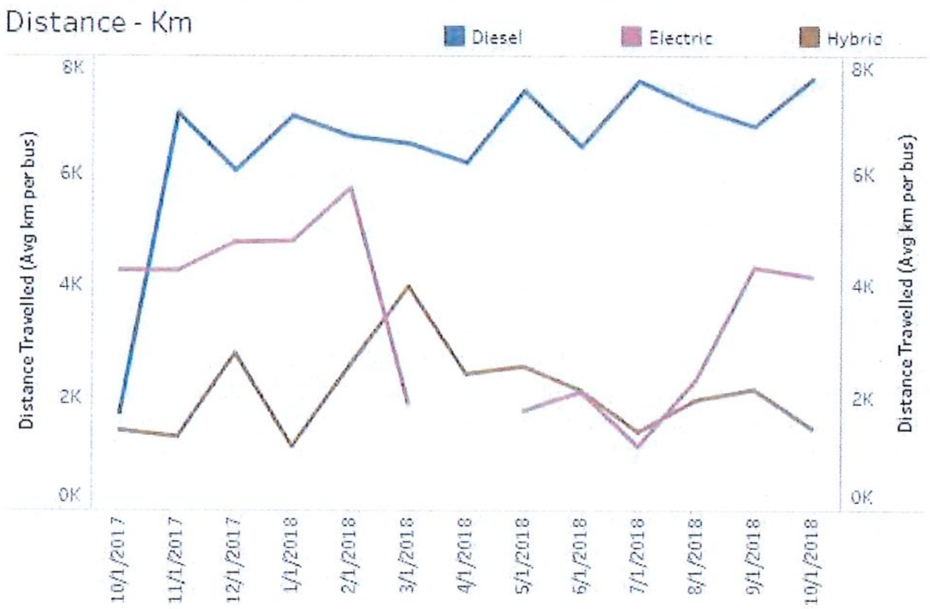

Figure 4 Average kilometres per bus type

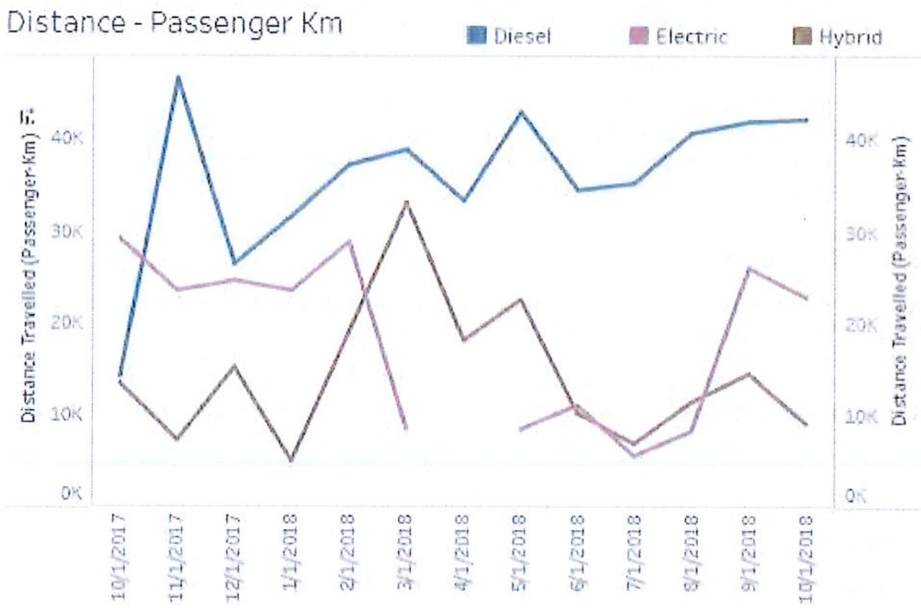

Figure 5 Average passenger - kilometres per bus type

4.3.3 Missed Peaks and Maintenance Efficiency

Table 13 provides a summary of missed peak services for the different bus types. The analysis included all commuter (AM and PM) peaks during weekdays, excluding public holidays.

It shows that the diesel buses performed much better than the electric or hybrid buses, with fewer unscheduled breakdowns for all months of the trial. The electric buses proved to be the most unreliable of the three trial bus types during the trial. They were off the road more than the other buses, not just because of the weight issue but also missed peak services due to unscheduled breakdowns and servicing requirements. The key issues were related to brake and suspension issues.

Table 13 Missed peaks during trial

Missed peak services per bus	Diesel	Electric	Hybrid
Scheduled	0.8%	1.2%	1.0%
Unscheduled (due to vehicle fault)	0.8%	35.7%	14.2%
Other unscheduled (due to accident, weight issue)	0.1%	7.5%	4.7%
Total	**1.7%**	**44.4%**	**19.9%**

Monthly variations in scheduled and unscheduled peaks missed is illustrated in Figure 6 and Figure 7. The diesel buses consistently showed greater reliability with fewer unscheduled peaks missed (Figure 6).

In November 2017, the hybrid and electric bus had similar levels of unscheduled missed peaks (Figure 6). The electric bus was serviced due to electrical ABS warnings and the hybrid bus experienced issues due to breakdowns.

There were two significant jumps in missed peaks for the hybrid bus (February 2018) and electric bus (June to August 2018). In February 2018, the large amount of unscheduled missed peaks for the hybrid bus was because the bus was broken down and did not operate for most days during the last half of month. The bus was experiencing ABS brake problems during the last week of February and therefore was taken out of service.

There were a significant number of unscheduled missed peaks for the electric buses in June to August 2018. Bus 711 (introduced to the trial in June 2018) had two safety issues, which effectively doubled the percentage of missed peaks for electric buses. The first was a faulty brake valve which prevented it from going into service post-delivery. The second happened at the end of June 2018 and involved buses rolling away without warning, resulting in the buses being taken out of service for almost two months. This was not repaired until mid-August 2018.

Bus 710 had an ABS issue from 11 July to 16 July, a suspension issue from 20 July to 8 August and a software issue from 11 August to 20 August 2018. Brake and suspension issues seemed to dominate the electric buses. This should be considered with any specification and procurement in future. Without these issues the missed peaks would be significantly reduced. Greater knowledge and on-site service and parts capability for an electric bus fleet could reduce down time.

The diesel buses had a high number of scheduled missed peaks in November as bus 639 was not operational during the month due to accident damage (Figure 7). In January, the higher number of scheduled missed peaks for the hybrid bus was because it was not operational during the school holiday period. The various scheduled missed peaks for all bus types in other months are mainly due to scheduled maintenance and public holidays.

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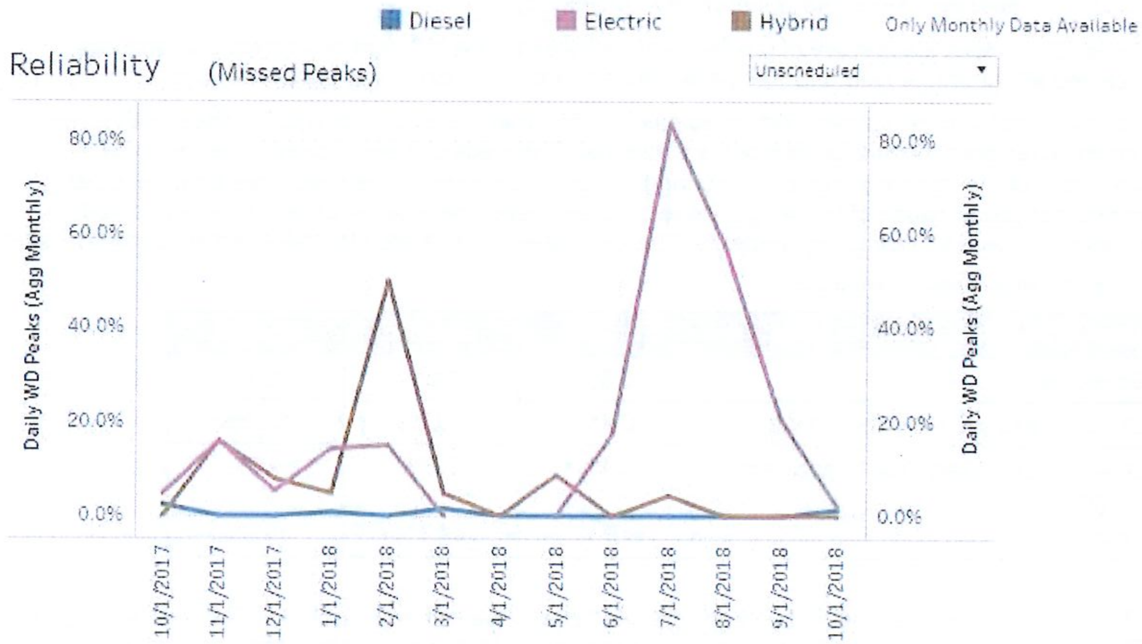

Figure 6 Unscheduled peaks missed per bus type

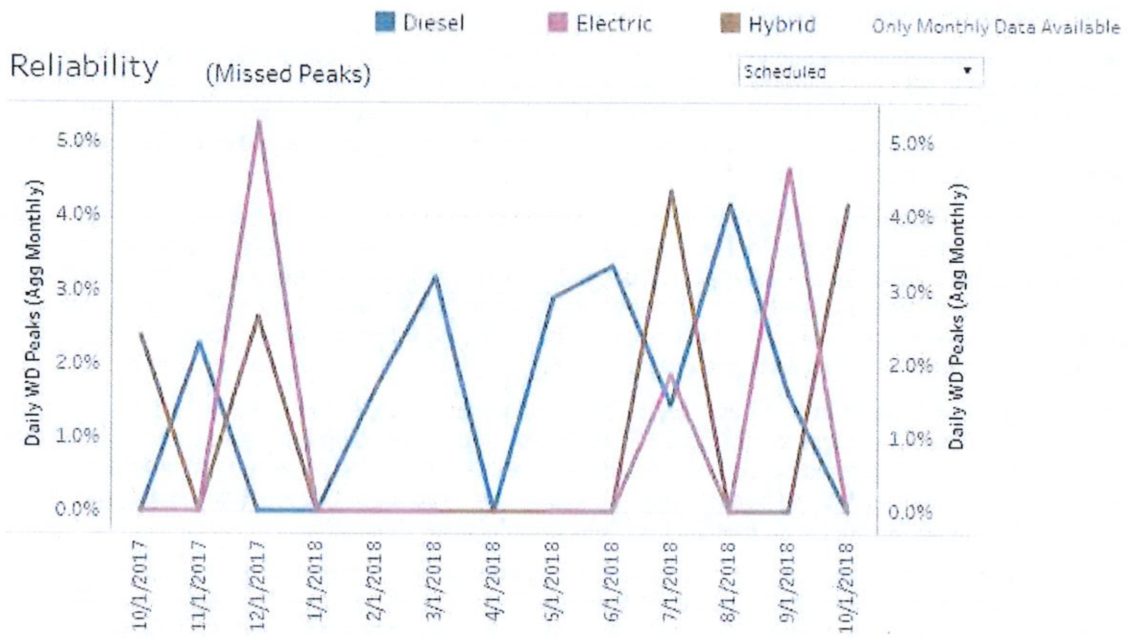

Figure 7 Scheduled peaks missed per bus type

4.3.4 State of Charge – Electric Bus batteries

The minimum daily state of charge of the battery in the electric buses shows significant variability over the months of operation to date (Figure 8). Generally, the minimum charge was above 20%.

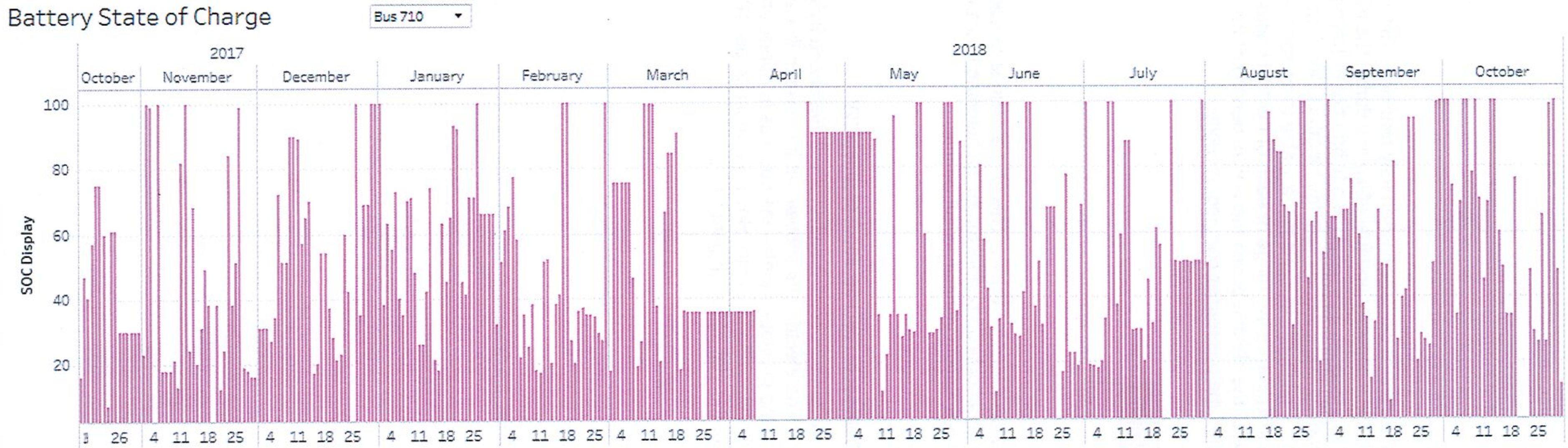

Figure 8 Monthly battery state of charge snapshot – Bus 710

4.3.5 Refuelling time

The refuelling time for electric buses is much longer than that for electric and hybrid buses. It takes six hours to charge electric buses from zero charge, whilst six minutes for refuelling diesel and hybrid buses from empty. The recharge/refuel time will vary depending on the battery state of charge or the amount of fuel left in the tank. During the trial battery charging times were not considered a factor as the two buses were easily scheduled to accommodate recharging. It is when there are significant numbers of electric buses at a depot and having to schedule enough time for recharging or managing buses that need to do double shifts with minimum turnaround time that recharging time could become an issue.

4.3.6 Range

The range is the maximum distance that a vehicle can travel when fully refuelled. This was calculated for each vehicle type using fuel tank or battery capacity and fuel efficiency during the trial. The outcome of this analysis is summarised in Table 14. The diesel and hybrid buses have a longer range than the electric bus, but all buses exceed the current maximum trip length undertaken by buses in the Transport Canberra fleet (about 350 km). That is, the trial buses were able to perform a day's work without the need to refuel or recharge and therefore the range of each of the trial buses was not a performance factor. However in the case of the electric buses the weight penalty of the carried battery banks to enable that range greatly affected the passenger carrying capacity.

Table 14 Range by bus type

Diesel	Electric	Hybrid
810 km	450 km	760 km

4.4 Operational Capacity

Capacity was assessed by the carrying capacity of the buses. This was a serious deficiency with electric buses having a passenger capacity of only 55 people for the first electric bus and 49 for the second bus, whilst the diesel and hybrid bus have a capacity of 68 people.

4.5 Operational Efficiency

Operational efficiency was assessed in relation to fuel use and fuel efficiency.

Fuel use per 100km was reasonably consistent across all months for the diesel and hybrid bus, other than November 2017 for the diesel buses. The electric bus showed an increase in the average fuel use per 100 km in May 2018 compared to the previous months the bus was in operation, potentially due to low travel and a higher proportion of standing/idle time. However, fuel use per 100km for the electric buses declined towards the end of the trial period (Figure 9).

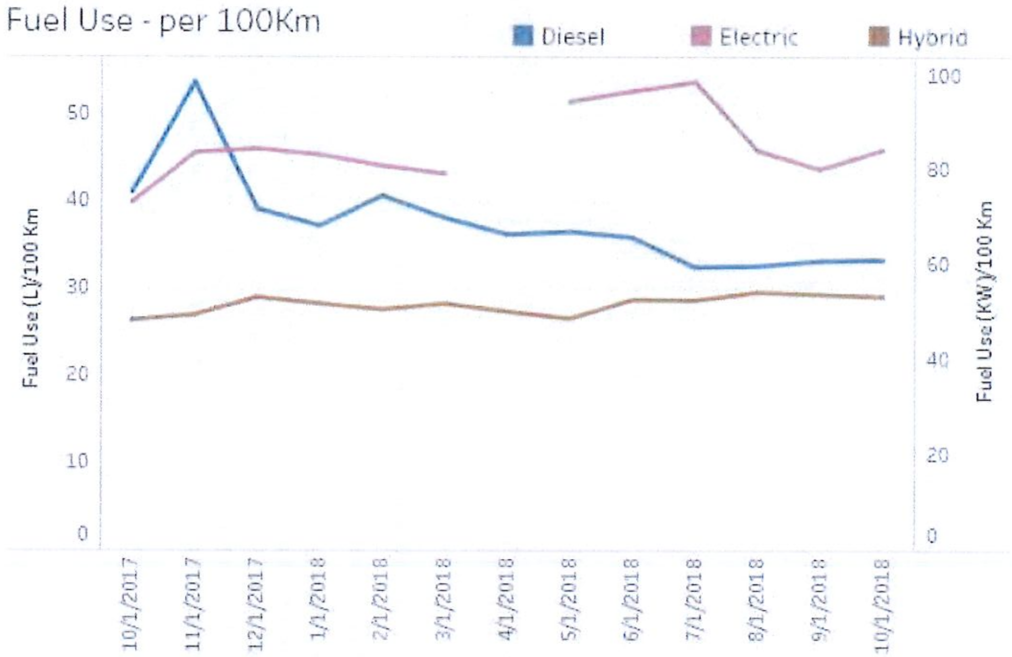

Figure 9 Fuel Use per 100 km per bus type

Fuel efficiency in $/km is very consistent across all months for the electric and hybrid buses (Figure 10). Diesel buses cost more per passenger-km, followed by the hybrid and lastly the electric buses. All energy prices in recent times have been quite volatile. This report is based on electricity prices for 2018. The new 2019 prices are substantially higher, but the electric bus would remain most efficient.

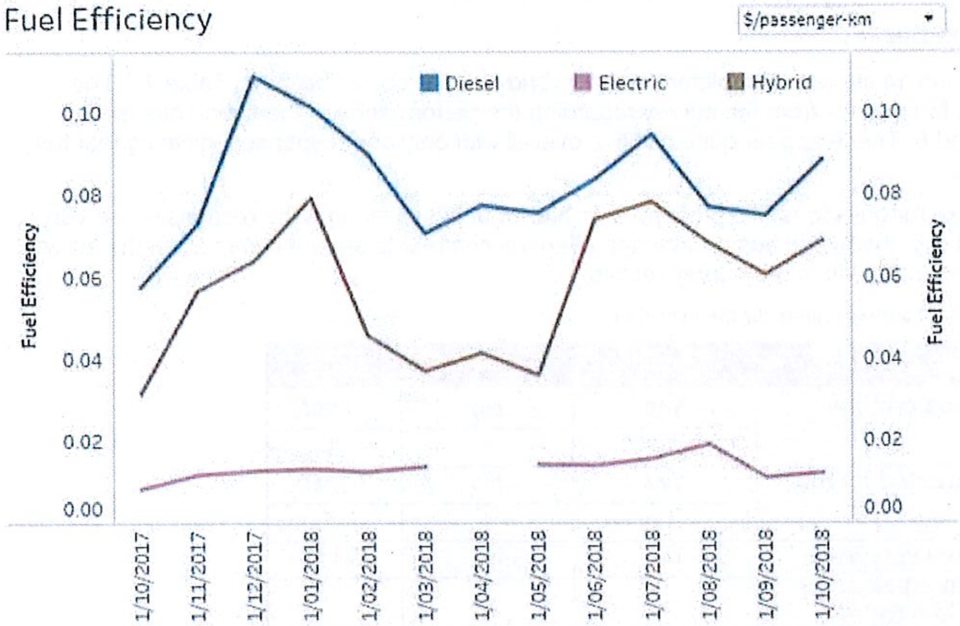

Figure 10 $/passenger-km per bus type

Fuel energy efficiencies show a similar pattern (Figure 11). In terms of kJ/passenger-km the diesel buses consume more energy followed by the hybrid and the electric which is the most energy efficient.

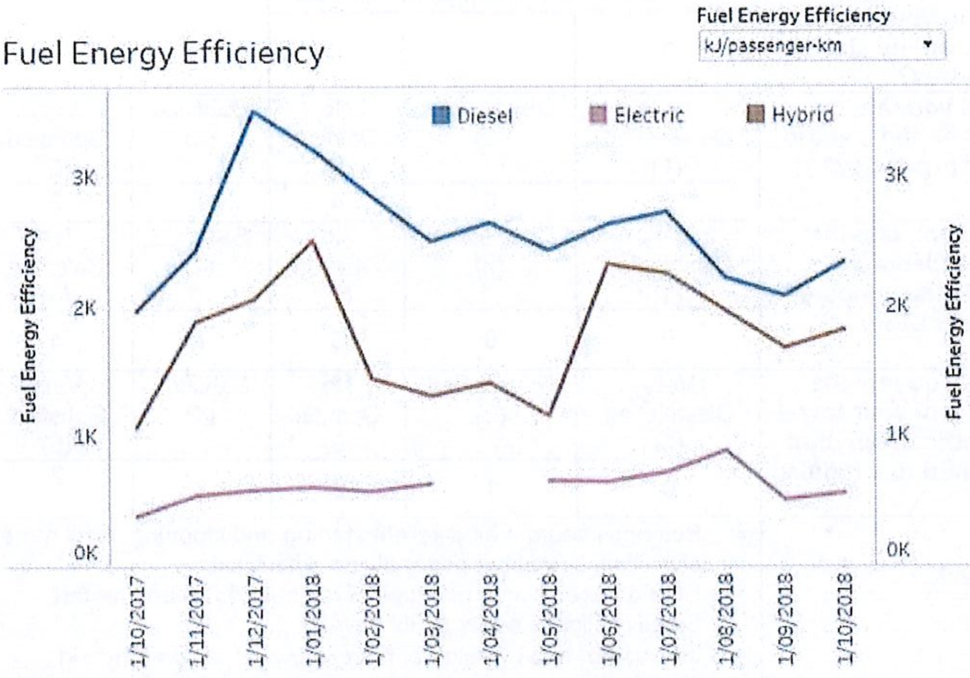

Figure 11 Fuel efficiency measured by kJ/passenger-km

4.6 Passenger Surveys

A total of 73 surveys were filled out and returned by passengers and of these 14 surveys were for the hybrid bus and 59 surveys were for the electric buses. The survey contained nine questions with the ninth question asking for general feedback. General feedback responses are listed and all responses are indicated in a tabular form in Table 15 and Table 16 below.

4.6.1 Hybrid Bus

The results from the 14 surveys completed for the hybrid bus are shown below in Table 15. The important results to consider from the survey regarding the performance of the hybrid bus are questions 6, 7 and 8. These appear quite positive overall with only one response indicating that they were dissatisfied.

The average score for questions 6 to 8 is approximately 4.0, indicating that the responses are very close to satisfied with the hybrid bus on average. General comments are not common on the survey and have no direct trend with other survey results.

Table 15 Summary of survey results for the hybrid bus

Number of Surveys Collected	14				
1. Was your bus on time today?	Yes	No	Other		
	10	1	3		
2. Were you greeted by the driver?	Yes	No	Other		
	12	1	1		
3. Did you know you were travelling on an electric bus/hybrid bus today?	Yes	No	Other		
	5	9			
4. Have you travelled on an electric bus/hybrid before?	Yes	No	Other		
	10	3	1		
5. Have you noticed any difference in your travel experience on the electric bus/hybrid bus?	Yes	No	Other		
	7	7	0		
6. How would you rate the noise level on the electric bus/hybrid bus today?	Very Dissatisfied (1)	Dissatisfied (2)	No Opinion (3)	Satisfied (4)	Very Satisfied (5)
	0	0	4	7	3
7. How would you rate the smell of the electric bus/hybrid bus compared to the regular bus service?	Very Dissatisfied (1)	Dissatisfied (2)	No Opinion (3)	Satisfied (4)	Very Satisfied (5)
	0	0	3	7	4
8. How would you rate the smoothness of your travel on the electric bus/hybrid bus compared to a regular service?	Very Dissatisfied (1)	Dissatisfied (2)	No Opinion (3)	Satisfied (4)	Very Satisfied (5)
	0	1	3	8	2
General Feedback	• Bus does seem a bit different starting and stopping. A bit more of a clunk sound but generally no difference. • Hybrid buses worse because of the shut down and restart. Smell is slightly better as its new. • If I was not told I would not have known I was on a hybrid electric bus. • Overall, the hybrid electric bus doesn't feel as comfortable as other modes on the blue rapid routes.				

4.6.2 Electric Buses

The results from the 59 surveys completed for the electric bus are shown below in Table 16. The important results to consider from the survey regarding the performance of the electric buses are questions 6, 7 and 8. These appear quite positive overall with only one response indicating that they were dissatisfied.

The average score for questions 6 to 8 is approximately 4.2, indicating that the responses are more than satisfied with the electric bus on average. General comments do not indicate any major problems with the electric buses with most comments referring largely to the buses fitout.

Table 16 Summary of survey results for the electric bus

Number of Surveys Collected	59				
Was your bus on time today?	Yes	No	Other		
	49	10	0		
Were you greeted by the driver?	Yes	No	Other		
	57	2	0		
Did you know you were travelling on an electric bus/hybrid bus today?	Yes	No	Other		
	28	31	0		
Have you travelled on an electric bus/hybrid before?	Yes	No	Other		
	35	21	3		
Have you noticed any difference in your travel experience on the electric bus/hybrid bus?	Yes	No	Other		
	32	27	0		
How would you rate the noise level on the electric bus/hybrid bus today?	Very Dissatisfied (1)	Dissatisfied (2)	No Opinion (3)	Satisfied (4)	Very Satisfied (5)
	0	1	11	24	20
How would you rate the smell of the electric bus/hybrid bus compared to the regular bus service?	Very Dissatisfied (1)	Dissatisfied (2)	No Opinion (3)	Satisfied (4)	Very Satisfied (5)
	0	0	17	17	25
How would you rate the smoothness of your travel on the electric bus/hybrid bus compared to a regular service?	Very Dissatisfied (1)	Dissatisfied (2)	No Opinion (3)	Satisfied (4)	Very Satisfied (5)
	2	0	9.5	23.5	25
General Feedback	• Quieter – 3 feedback responses • More jerky with stopping and starting, not enough room in the luggage rack and jerks a lot especially for people with motion sickness. • Not many buttons to signal stops – 2 feedback responses • Fittings are not as durable and will not last as long, looks and feels cheap. • Just a different form of propulsion • Driver smiled and experience was smoother				

4.7 Conclusions

The operational assessment reflected feedback from various technical data collection and responses from driver and passenger surveys. It clearly indicated that the diesel buses performed better than electric or hybrid buses in relation to all operational criteria, other than fuel efficiency.

In terms of operational capability the diesel bus performed best against most of the performance criteria used in the benchmark tests, with key strengths being internal noise at 50 km/h, seating capacity and turning circle. Driver surveys also showed a preference for diesel buses rather than electric or hybrid buses. This is because the diesel buses are considered more reliable, quieter and easier to drive, having better acceleration and braking. Acceleration was highlighted as a weakness of hybrid buses during benchmark tests, but braking of all buses was considered satisfactory. Drivers would consider electric buses if the technology improved in terms of reliability and acceleration.

The main factor limiting the operation of electric buses was their exceedance of legal weight restrictions under the Road Transport (Mass, Dimensions and Loading) Regulation 2010. This resulted in the electric buses being off the road for seven weeks or more whilst Transport Canberra obtained a temporary permit for them to operate on Canberra roads. It is a major obstacle for their future use and integration with existing options, but may be overcome by future technological improvements.

In terms of operational reliability the diesel buses performed much better than the electric or hybrid buses, with less unscheduled breakdowns for all months of the trial. The electric buses proved to be most unreliable during the trial. They were off the road more than other buses, not just because of the weight issue but also missed peaks due to unscheduled breakdowns. The key issues were related to brake and suspension issues; not due to battery system performance (other than weight), but was due to other build quality issues. Better build quality and more local supplier familiarity with the electric vehicle and spare parts could reduce downtime and improve reliability in future.

The driver surveys indicated driver concerns and uncertainty regarding the reliability of electric buses, including available range. However, on-board monitoring of electric buses indicated that the state of charge was generally higher than 20%, but did show high variability.

In terms of operational capacity the diesel buses performed much better than the electric or hybrid buses. The electric buses have a serious deficiency in relation to passenger capacity; being able to carry up to only 55 people, whilst the diesel and hybrid buses can carry up to 68 people. This weakness is also reflected in the relatively low passengers carried during the trial.

In terms of operational efficiency the electric buses performed best, both in terms of dollars and kJ per passenger kilometre. This is also reflected in the environmental performance discussed in Chapter 6.

Passenger surveys on electric and hybrid buses indicated that the performance of these buses in relation to noise, smell and smoothness of travel was satisfactory. The responses were more positive for the electric buses than the hybrid buses.

5.0 Environmental Assessment

5.1 Introduction

In 2016-17, transport was the second largest contributor to ACT greenhouse gas emissions accounting for 29 per cent of emissions after electricity (52 per cent) (ACT Government, 2017). As the electricity supply will be 100 per cent renewable (zero emissions) by 2020, the ACT is now focused on targeting emissions reductions in transport, natural gas and waste.

Transport is expected to create over 60 per cent of the ACT's emissions by 2020, with the majority created by the use of private cars.

An environmental assessment has been undertaken to analyse the environmental performance of different bus technologies and the potential benefits that may arise from adopting these technologies, particularly in relation to meeting emissions reductions targets within the ACT.

5.2 Environmental Policies and Objectives

5.2.1 Climate Change and Greenhouse Gas Reduction Act 2010

The *ACT Climate Change and Greenhouse Gas Reduction Act 2010* (the Act) aims to promote the development of policies and practices to address climate change, to set targets to reduce greenhouse gas emission and to provide for monitoring and reporting in relation to the targets within the ACT.

The principal target (*the ACT target*) set out in the Act is to reduce greenhouse gas emissions in the ACT to achieve zero net emissions by 2045. Zero net emissions means that any emissions of greenhouse gas in the ACT are balanced by avoidance and mitigation activities and emissions offsets outside the ACT. The *interim target* is to reduce greenhouse gas emissions in the ACT to 40 per cent less than 1990 emissions by 2020. The *per person target* is for the average amount of greenhouse gas emissions produced per person in the ACT each year to peak by 30 June 2013.

The ACT Government is required to report to the Legislative Assembly on the Territory's greenhouse gas emissions and targets each financial year. In 2016-17, the ACT achieved the *per person target* where the amount of greenhouse gas emissions (in carbon dioxide equivalent, CO_2-e) generated per person in the ACT has declined since 2013. In 2016-17, the ACT emitted 9.64 tonnes of CO_2-e per person. This was a further reduction from 2015-16 when emissions where 10.14 tonnes of CO_2-e per person. In 2005-06, ACT per person emissions peaked at 12.72 tonnes of CO_2-e per person (ACT Government, 2017).

The Climate Change Council (the Council) was established by the ACT Government under the Act in 2011 with the function to advise the Minister for Climate Change and Sustainability on matters relating to reducing greenhouse gas emissions and addressing and adapting to climate change.

5.2.2 AP2

The ACT Government has developed AP2 which outlines the ACT's strategy to meet the targets set out under the Act. An integrated policy approach has been taken to developing the actions outlined in AP2 and adopts a sectoral approach to identifying and targeting emission reductions. The transport sector, along with the residential, non-residential, waste and energy supply sectors, has been identified as a major source of emissions from the community. Table 17 shows the potential contribution each sector can make to achieve the 2020 emission reductions target.

Chapter 6 of AP2 describes the business as usual projections and how Transport for Canberra will reduce greenhouse gas emissions (i.e. mode shifting and increasing vehicle fleet efficiency). It also describes how the ACT Government supports electric vehicles.

The AP2 provides one action (Action 10) for reducing transport sector emissions: *the ACT Government will implement the Transport for Canberra policy, and develop a Low Emissions Vehicle Strategy.*

Table 17 Targeted emission reductions by sector

Sector	Emissions reduction in 2020 (tonnes CO_2-e)
Residential sector energy use	218,000
Non-residential sector energy use	181,000
Transport sector emissions	**138,000**
Waste sector emissions	16,000
Energy supply sector emissions	1,471,000
Total	**2,024,000**

Source: ACT Government, 2012

5.2.3 Transport for Canberra: Transport for a Sustainable City 2012-2031

Transport for Canberra is the ACT Government's foundation for transport planning for the next 20 years. It updates and replaces the 2004 Sustainable Transport Plan. Transport for Canberra sets a new policy direction for transport and is guided by six principles:

- transport and land use integration
- active travel
- sustainable travel options and reducing transport emissions
- safety
- accessibility
- efficiency and cost-effectiveness.

These principles also guide the 34 action items to be implemented to support a shift to a more sustainable transport system including:

- Action 4: Grow the bus fleet to respond to patronage growth and deliver the Frequent Network, and ensure the new bus fleet minimises greenhouse gas emissions, maximises patronage potential and obtains value for money for the Territory
- Action 25: Release a low emission vehicle strategy, including an evaluation of the Green Vehicles Duty Scheme to identify how it could better encourage the purchase of lower emissions vehicles including electric vehicles

Overall, Transport for Canberra will contribute to the ACT's greenhouse gas emissions reduction targets by increasing the efficiency of public and private vehicles and encouraging more people to choose sustainable transport.

5.2.4 ACT's Transition to Zero Emissions Vehicles Action Plan 2018-21

The ACT's transition to zero emissions vehicles action plan 2018-21 (the plan) outlines the actions to be implemented to support the rapid uptake of zero emissions vehicles in the ACT as part of the broader plan to ensure Canberra grows into a highly sustainable and liveable city.

'Zero emissions vehicle' refers to vehicles that do not emit any greenhouse gas emissions, and includes plug-in hybrid electric, battery electric and hydrogen fuel cell electric cars, as well as electric bikes:

Battery electric vehicle: fuelled solely by electricity and does not use any conventional fuels

Plug-in hybrid electric vehicle: fuelled by electricity as well as having either a petrol or diesel tank to extend the range of the vehicle for long trips. These vehicles can be run either on electricity or fuel, but are considered zero emissions vehicles as it is most likely the vehicle will be run on electricity for the majority of trips.

Fuel cell electric vehicle: uses a fuel cell to power an electric motor. Fuel cells use oxygen from the air and compressed hydrogen as fuel. Hydrogen that is created using renewable electricity is a zero emissions fuel source.

A hybrid vehicle is not considered to be a zero emissions vehicle as it uses an engine powered solely by petrol, diesel or LPG with an electric motor and battery recovering deceleration energy and boosting efficiency.

The results of this trial will provide information on issues to consider in making the transition to a zero emissions bus fleet.

5.3 Environmental Performance

In order to analyse the environmental performance of electric bus technologies relative to conventional diesel technologies, the following parameters for each bus type was analysed:

- Emissions, specifically:
  - Greenhouse gas (GHG) emissions
  - Particulate matter emissions – PM_{10}
  - Nitrogen oxide (NOx).
- Other environmental considerations such as noise, end of life options and repair and maintenance have also been addressed.

It is noted that the trial began during mid-October 2017 and ran until the end of October 2018. Therefore, the total emissions during October-2017 is lower than that of the other months.

5.3.1 Emissions

To calculate total emissions produced by an activity, the type of emissions is classified into direct and indirect emissions (Commonwealth Department of Environment and Energy (DoEE), 2018):

- **Direct emissions**: produced from sources within the boundary of an organisation and as a result of that organisation's activities (e.g. generation of energy, heat, steam, transportation of materials, products, waste and people, fugitive emissions such as natural gas leaks from joints and seals, on-site waste management such as emissions from landfills).
- **Indirect emissions**: generated in the wider economy as a consequence of an organisation's activities, but which are physically produced by the activities of another organisation. The most important category of indirect emissions is from the consumption of electricity. Other examples include upstream emissions generated in the extraction and production of fossil fuels, downstream emissions from transport of an organisation's product to customers.

Emission factors are used for calculating GHG emissions by multiplying the factor which is generally expressed in the form of a quantity of a given GHG emitted per unit of energy (e.g. kg CO_2-e/GJ, tCH_4/t coal) with the activity data (e.g. kilolitres x energy density of petrol used). All factors are standardised by being expressed as a carbon dioxide equivalent (CO_2-e).

An emission factor is activity-specific where the activity determines the emissions factor that is used. The scope that emissions are report under is determined by whether the activity is within the organisation's boundary (direct –scope 1) or outside it (indirect – scope 2 and scope 3). Examples of scope 1, scope 2 and scope 3 emissions are presented in Table 18. This study has quantified Scope 1 and Scope 2 emissions.

Table 18 Emission scopes

Emissions	Definition	Relevant examples
Scope 1 (GHG-1)	Emissions released to the atmosphere as a direct result of the activity, or series of activities at a facility level.	Emissions from the burning of fuel used for the buses.
Scope 2 (GHG-2)	Emissions released to the atmosphere from the indirect consumption of an energy commodity.	Use of electricity produced by the burning of coal in another facility to charge the electric bus battery, electricity use in the workshop for service and maintenance of the buses.
Scope 3	Indirect emissions that are generated in the wider community and occur as a consequence of the activities of a facility, but from sources not owned or controlled by that facility's business.	Use of sold products, end-of-life treatment of sold products, employee commuting, waste generated in operations, business travel.

5.3.1.1 Total kilometres

The total kilometres travelled throughout the trial period averaged for each bus type is presented in Figure 12. The diesel bus travelled significantly higher kilometres compared to the hybrid or electric buses. This may in part be due to the routes assigned to each bus, but mainly as a result of the reliability of both the electric and hybrid buses. As a result the diesel buses also carried more passengers. The limited carrying capacity of the electric buses may also have been a factor in this result.

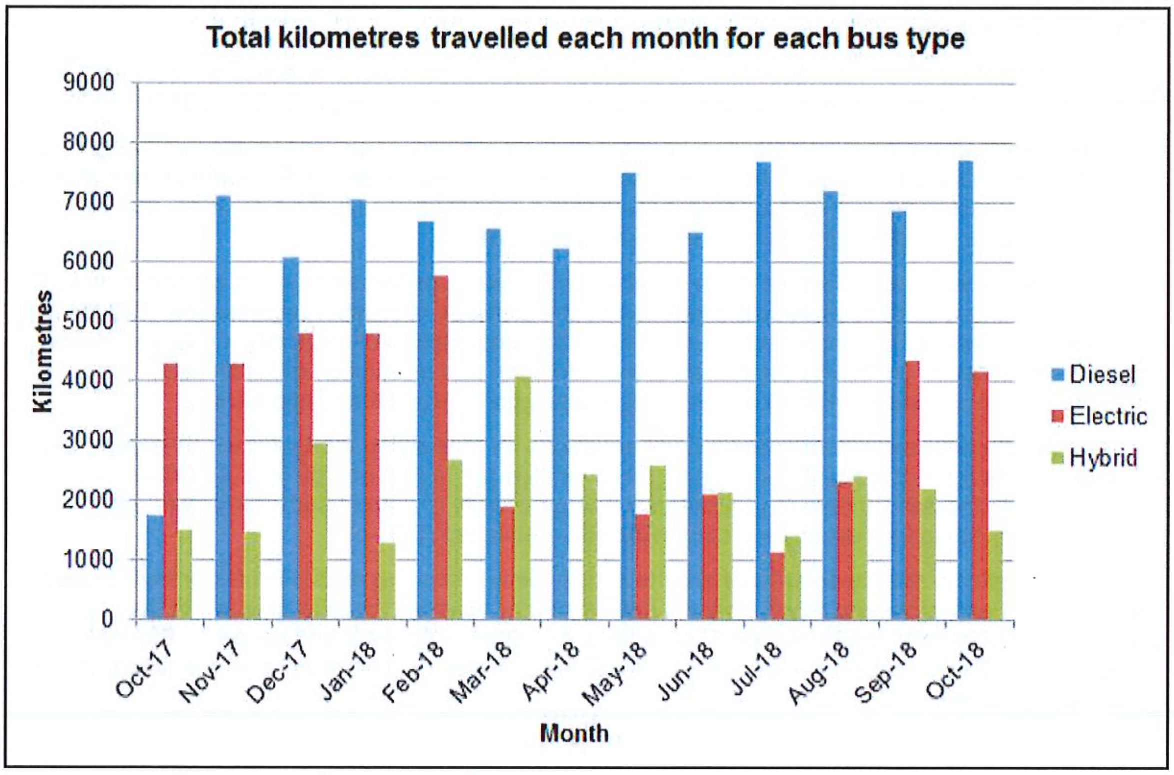

Figure 12 Total kilometres travelled each month for each bus type

5.3.1.2 Passenger-kilometres

The passenger-kilometres travelled throughout the trial period for each bus type is presented in Figure 13. With the exception of October 2017, the diesel bus travelled the most passenger-kilometres each month, ranging from approximately 26,000 to 47,000 passenger-kilometres.

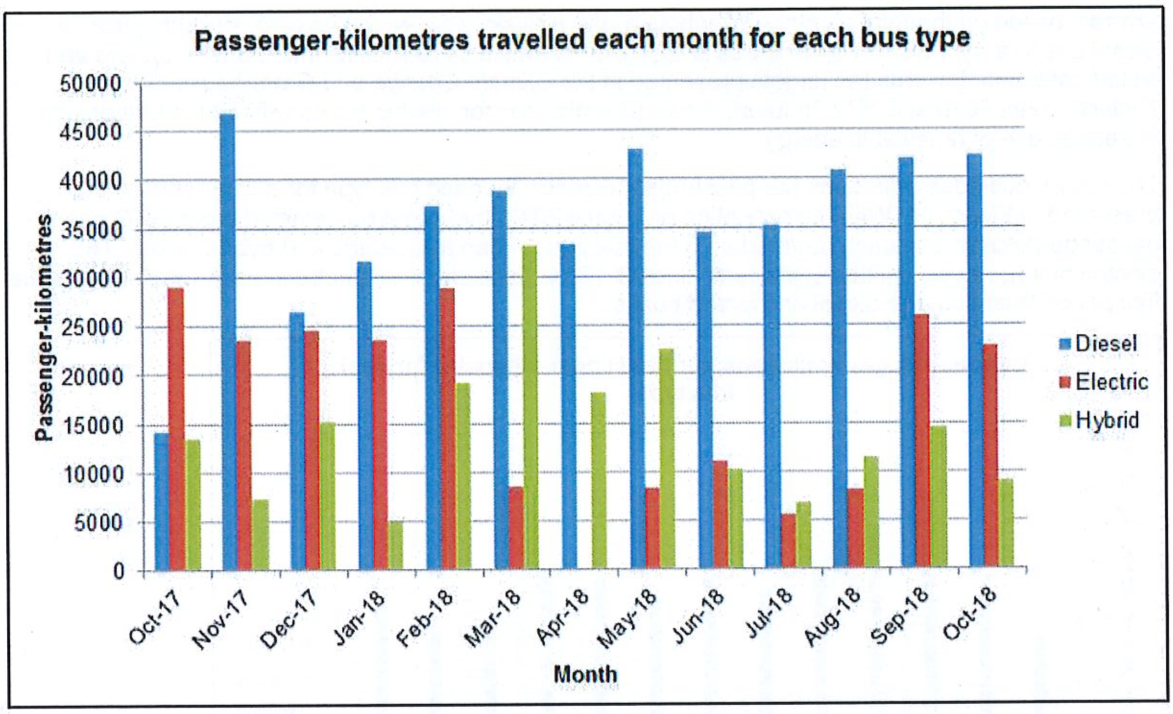

Figure 13 Passenger-kilometres travelled each month for each bus type

The electric bus travelled the most passenger kilometres during October 2017 to February 2018, September 2018 and October 2018, travelling around 25,000 passenger-kilometres down to about 10,000 passenger-kilometres in March, May, June, July and August 2018. The electric bus was not operational during April 2018.

The hybrid bus generally travelled less than 15,000 passenger kilometres each month except for February, March, April and May 2018, reaching approximately 33,000 passenger-kilometres in March 2018.

Total emissions are directly related to the amount of fuel consumed. Given that the trial buses travel differing amounts of kilometres and carry different passenger loads a reasonable comparison of emissions by different bus types can be provided by expressing emissions as a function of passenger-kilometres. Alternatively, the emissions per passenger kilometre can be converted to expected emissions for a bus travelling a typical number of kilometres. On average, Canberra buses travel about 63,000 kilometres per year, so this can be used to determine a comparative estimate of annual emissions.

5.3.1.3 Greenhouse gas (GHG) emissions

The total GHG emissions per year by bus type is summarised in Table 19, based on each bus travelling 63,000 km per year. It shows that the electric bus would produce much less GHG emissions than diesel or hybrid buses. Throughout the trial period, the greatest amount of greenhouse gas were emitted in November 2017 by the diesel bus with approximately 8 tonnes CO_2-e produced.

Table 19 GHG emissions by bus type

Parameter	Diesel	Electric	Hybrid
GHG emissions per km	995.7 g/km	25.3 g/km	811.7 g/km
GHG emissions per year	62.7 t/year	1.6 t/year	51.1 t/year

Note: 1. Based on typical bus travelling 63,000 km per year.

2. Uses 2019/20 weighted average emissions intensity from Saddler (2017)

Overall, based on the total monthly greenhouse gas emissions for each bus type, switching from a diesel bus to a hybrid or an electric bus is expected to emit less total GHG into the atmosphere and would contribute towards the targets presented in the *Climate Change and Greenhouse Gas Reduction Act 2010* and AP2. In future the GHG emissions for electric buses will reduce further with increased use of renewable energy.

The greenhouse gas emissions per passenger-kilometre for each bus type for each month is presented in Figure 14. With the exception of August 2018, the diesel bus emitted more GHG per passenger-kilometre in each month during the trial period than the electric and hybrid buses. The electric bus however, emitted significantly less GHG per passenger-kilometre in each month during the trial period than both the diesel and hybrid buses.

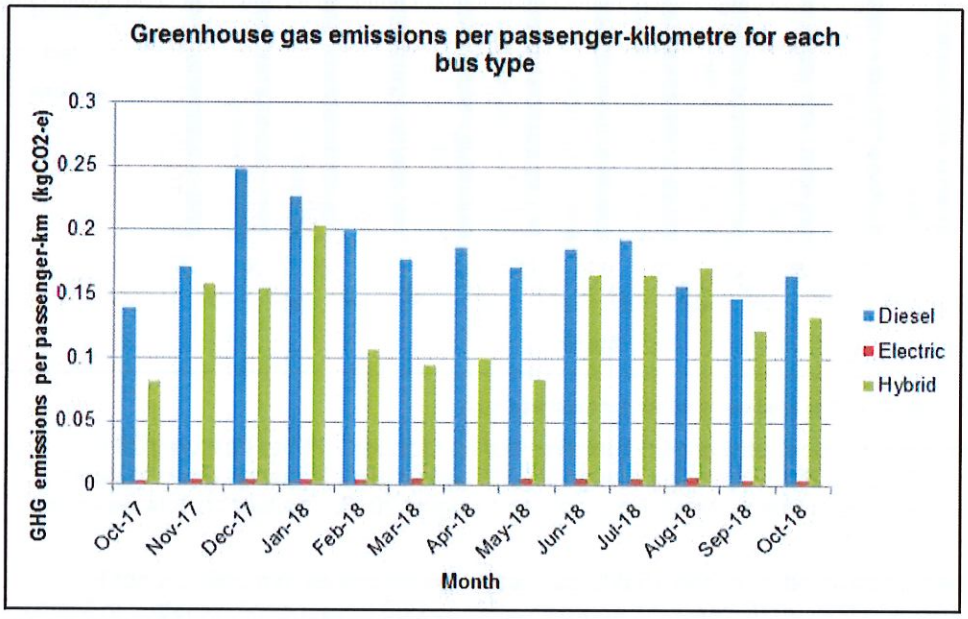

Figure 14 Greenhouse gas emissions per passenger-kilometre for each bus type

5.3.1.4 Particulate matter emissions – PM10

Total PM10 emissions takes into account both exhaust emissions and non-exhaust emissions (i.e. emissions from brakes and tyres). The total PM10 emissions per year by bus type is summarised in Table 20, based on each bus travelling 63,000 km per year. It shows that once the data is normalised, the electric bus would produce only slightly less PM10 emissions than diesel buses.

Table 20 PM10 emissions by bus type

Parameter	Diesel	Electric	Hybrid
PM10 emissions per km	77.0 g/km	73.6 g/km	112.1 g/km
PM10 emissions per year	4.9 kg/year	4.6 kg/year	7.1 kg/year

Note: Based on typical bus travelling 63,000 km per year.

The hybrid bus has been built to Euro V standards whereas the diesel bus has been built to the more stringent Euro VI standards to reduce exhaust emissions levels. In this trial, the Euro V/VI standards apply to the PM10 emissions and NO_x emissions (discussed in the following section). The difference between the Euro V and Euro VI engines is clearly evident in this trial whereby the Euro V hybrid bus produces the most PM10 emissions, despite the anticipated fuel efficiency associated with the battery in the hybrid.

The diesel bus, having a Euro VI engine, was comparable to the electric bus in terms of the amount of PM10 emissions produced.

The electric bus PM10 emissions comprise of non-exhaust emissions only. As a result, the electric bus produced less PM10 emissions than that of the diesel.

The PM10 emissions per passenger-kilometre for each bus type is presented in Figure 15. It shows that the diesel and electric buses have comparable PM10 emissions and they are generally much less than those for the hybrid. The hybrid bus produced the most PM10 emissions per passenger kilometre for ten months out of the 12-month trial period. This can be attributed to the Euro V engine used in the hybrid bus compared with the Euro VI engine used in the diesel bus.

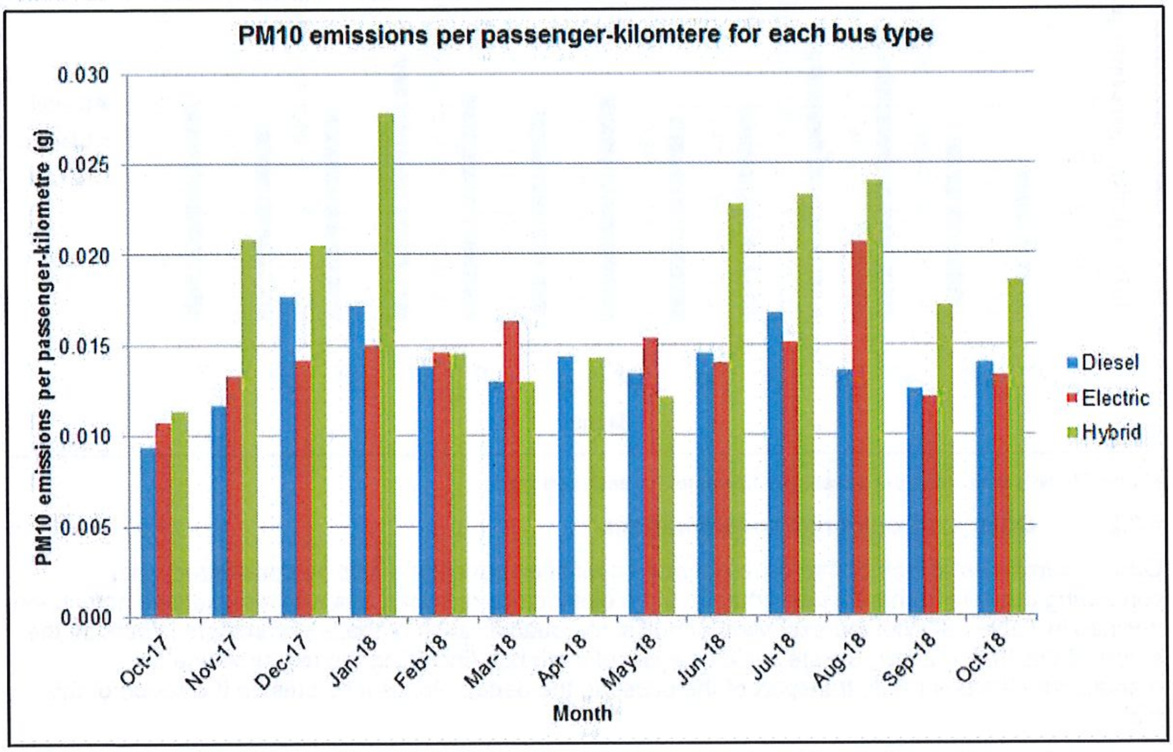

Figure 15 PM10 emissions per passenger-kilometre for each bus type

5.3.1.5 NO_x emissions

The total NO_x emissions per year by bus type is summarised in Table 21, based on each bus travelling 63,000 km per year. The hybrid bus produced the most NO_x emissions because of its Euro V engine.

Table 21 NO_x emissions by bus type

Parameter	Diesel	Electric	Hybrid
NO_x emissions per km	454.0 g/km	0.0 g/km	658.1 g/km
NO_x emissions per year	28.6 kg/year	0 kg/year	41.5 kg/year

Note: Based on typical bus travelling 63,000 km per year.

It is noted that NO_x is produced from the reaction of nitrogen and oxygen gases in the air during combustion and assuming the electric bus has zero exhaust emissions, the NO_x emissions factor for the electric bus is 0.0 g/km.

As mentioned in the previous section, the hybrid bus has a Euro V engine whereas the diesel bus has a Euro VI engine that meets a more stringent standard. As a result, the hybrid bus produces more NO_x emissions, despite the fuel efficiency associated with the battery in the hybrid.

The NO_x emissions per passenger-kilometre produced by each bus type during the trial period is presented in Figure 16. The hybrid bus produced the most NO_x emissions per passenger kilometre for nine months out of the 12-month trial period.

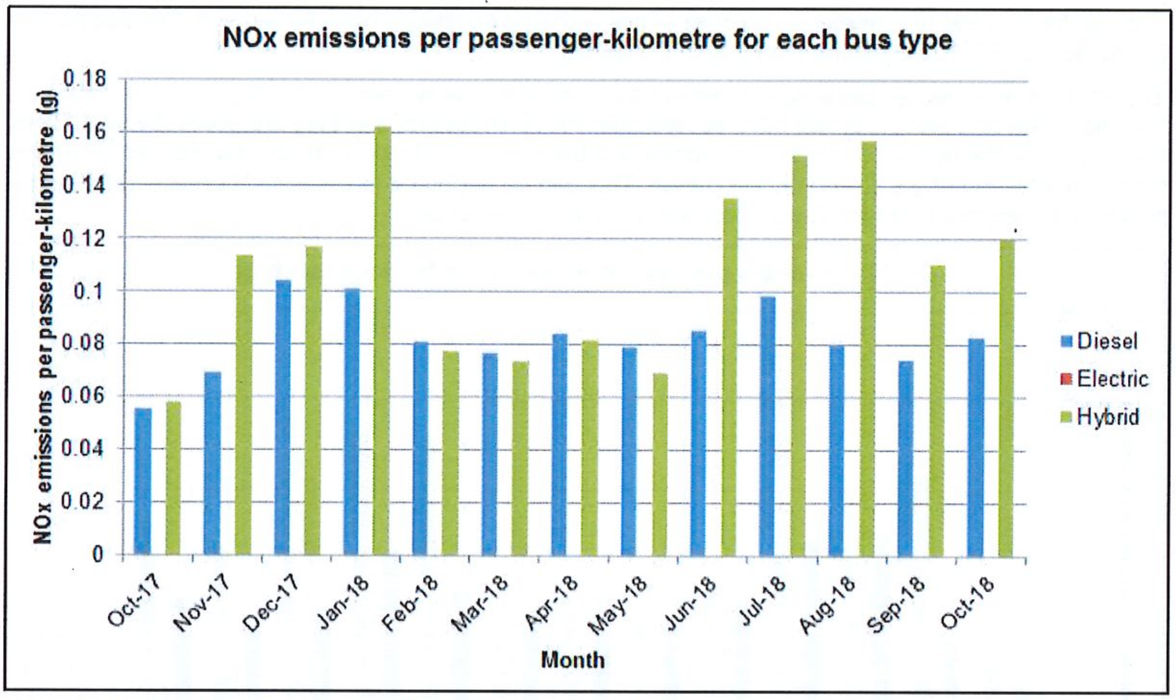

Figure 16 NO_x emissions per passenger-kilometre for each bus type

5.3.2 Other environmental considerations

Other environmental factors that have not been quantified but should also be considered when comparing the environmental performance of an electric bus or hybrid bus with a diesel bus have been outlined in Table 22. With the exception of noise, the quantification of these parameters is outside the scope of this trial. Further, the life cycle analysis of each bus (including the resource use to manufacture the bus parts, transport of the buses to the depot, etc.) is also outside the scope of this trial.

Table 22 Comparison of other environmental factors

Environmental factor	Comparison
Noise	Standard benchmark acceptance test were undertaken for each of the trial buses, the results of which are presented in Appendix A. For noise, each bus passed the acceptance level. The diesel bus (58-61 dB(A) from front to rear) was quieter for internal noise (at 50 km/h) than both the electric (66.5-68 dB(A) from front to rear) and the hybrid (66-68 dB(A) from front rear) buses. For internal noise (stationary) the electric bus and hybrid bus had the same noise level as the background with no engine noise whereas the diesel bus had an internal stationary noise level of 49-58 dB(A) from front to rear. For external noise (drive-by) the hybrid bus had the lowest noise level at 75.7 dB (A) followed by the electric bus at 77.7 dB (A) with the diesel bus being the noisiest at 79.9 dB (A). For external noise (compressor and brake) the diesel was the most quiet at 66.6dB(A) followed by the electric bus at 69.6dB(A) and then the hybrid bus at 70.6 dB(A).

Environmental factor	Comparison
	Further, of the 59 driver and passenger surveys completed for the electric bus, 20 people (34%) rated the noise level as a 5 (very satisfied), 24 (41%) rated the noise level as a 4 (satisfied), 11 (19%) rated the noise level as a 3 (no opinion) and 1 (6%) rated the noise level as a 2 (dissatisfied). Similarly, of the 14 driver and passenger surveys completed for the hybrid bus, 3 (21%) people rated the noise level as a 5 (very satisfied), 7 (50%) rated the noise level as a 4 (satisfied), 4 (29%) rated the noise level as a 3 (no opinion) and none rated the noise level as a 2 (dissatisfied) or 1 (very dissatisfied). Overall, diesel bus was quieter than the hybrid and electric buses internally at 50 km/h and externally at the compressor and brake) but the hybrid/electric busses were quieter during an external drive by and while stationary (internal). Drivers and passengers were overall satisfied with the noise level of the electric and hybrid buses, however it is unknown what the drivers/passengers thought of the noise level on the diesel bus.
End of life options	The end of life options for each of the bus types should be taken into account, specifically the recycling or disposal of the batteries within the hybrid and electric buses.
Repair and maintenance	The repair and maintenance requirements for each of the bus should also be taken into account, including whether the inputs into maintain and repairing an electric/hybrid bus would offset the potential benefit. For example, given the battery of the electric bus degrades with charging and use, what would be the environmental cost (i.e. manufacturing, freight, etc.) of replacing the battery.

5.4 Conclusions

Overall, the following conclusions can be made based on the environmental assessment undertaken for this trial:

- With the exception of October 2017, the diesel bus travelled the most total kilometres each month and therefore emitted the most greenhouse gases, PM10 and NO_x emissions each month throughout the trial period.
- The electric bus would produce much less GHG emissions than diesel or hybrid buses.
- With the exception of August 2018, the diesel bus emitted the most greenhouse gases per passenger-kilometre each month throughout the trial period.
- Taking into account the distance and number of passengers carried, there is not a significant difference between the amount greenhouse gases produced by the diesel bus and hybrid bus per passenger-kilometre.
- The hybrid bus produced the most PM10 emissions per passenger kilometre for ten months out of the 12-month trial period. This can be attributed to the Euro V engine used in the hybrid bus compared with the Euro VI engine used in the diesel bus.
- The majority of PM10 emissions is produced from the brakes and tyres, rather than from the exhaust.
- The hybrid bus produced the most NO_x emissions per passenger kilometre for nine months out of the 12-month trial period. This can be attributed to the Euro V engine used in the hybrid bus compared with the Euro VI engine used in the diesel bus.
- The diesel bus was the quietest bus internally at 50km/h and externally at the compressor and brake. The hybrid and electric bus were the quietest buses while stationary internally and externally (drive by).

Overall, switching from a diesel bus to a hybrid or electric bus would contribute to the reduction in greenhouse gas emissions targets outlined in the *Climate Change and Greenhouse Gas Reduction Act 2010* and the AP2. A hybrid vehicle is not considered to be a zero emissions vehicle as it uses an engine powered solely by petrol, diesel or LPG with an electric motor and battery recovering deceleration energy and boosting efficiency. The electric bus would offer significant reduction to GHG emissions.

In terms of PM10 and NOx emissions however, the diesel bus proved to be more efficient overall than the hybrid bus based on the Euro VI standard engine used in the diesel bus compared with the Euro V standard engine used in the hybrid bus. There would have to be a fuel efficiency of over 80% for the difference in the Euro standards to be negated.

6.0 Economic and Financial Assessment

6.1 Inputs

The trial data used in the economic analysis was based on data collected over the whole period of the trial (i.e. from October 2017 through to October 2018). The data was organised as monthly data which has been averaged and annualised for the appraisal. It has been used as an input to financial and economic modelling, on which the projections in Section 6.2 are based.

The key data inputs that were collected, per bus, included:

- Total vehicle kilometres travelled per month
- Passenger boardings per month
- Passenger revenue per month
- Maintenance and service costs accrued per month
- Total fuel cost per month
- Missed peaks per month.

These inputs are presented in Table 23 through to Table 28.

All buses were new at commencement of the trial. The type and identification number of each bus are:

- Diesel buses: Bus 639, Bus 640 and Bus 641
  - Make: Scania, model: K320UB 4x2 Euro VI EEV
- Electric buses: Bus 710 and Bus 711
  - Make: Carbridge, model: Toro eBus
- Hybrid bus: Bus 712
  - Make Volvo, model: B5RLRH.

Bus 711 had negligible operation time (refer Table 23) due to it being unavailable for over half the trial period. Accordingly, it has been excluded from the 20-year cost benefit appraisal as it has been assumed that including this data over the entire appraisal period would not reflect the expected average operation over the next 20 years. Although Bus 711 has been excluded from the analysis, its performance and any challenges associated with its operation should be considered by Transport Canberra and City Services (TCCS) in any future vehicle procurement.

The assumptions used in the analysis have been agreed in consultation with TCCS.

Table 23 Trial results – monthly vehicle kilometres travelled

Bus	Oct 17	Nov 17	Dec 17	Jan 18	Feb 18	Mar 18	Apr 18	May 18	Jun 18	Jul 18	Aug 18	Sep 18	Oct 18	Trial total	Trial average month
639	10	5	5,173	7,107	6,343	6,680	6,682	7,847	7,175	8,159	7,778	7,072	7,467	77,498	5,961
640	2,700	6,767	6,652	6,574	6,818	5,319	5,592	7,007	6,181	7,010	6,230	6,780	7,919	81,549	6,273
641	2,478	7,408	6,397	7,453	6,882	7,566	6,578	7,558	6,138	7,840	7,564	6,720	7,721	88,303	6,793
710	4,284	4,277	4,810	4,844	5,801	1,900	25	3,551	3,193	2,214	2,133	3,870	3,806	42,528	3,271
711	-	-	-	-	-	-	-	15	971	59	2,514	4,792	4,523	12,859	2,572
712	1,512	1,454	2,943	1,287	2,595	4,081	2,438	2,600	2,141	1,407	2,413	2,208	1,486	29,289	2,253
Diesel average	1,729	4,727	6,074	7,045	6,681	6,522	6,284	7,471	6,498	7,670	7,191	6,857	7,702	82,450	6,342

Table 24 Trial results – monthly boardings per bus

Bus	Oct 17	Nov 17	Dec 17	Jan 18	Feb 18	Mar 18	Apr 18	May 18	Jun 18	Jul 18	Aug 18	Sep 18	Oct 18	Trial total	Trial average month
639	410		1,887	3,039	3,507	3,482	2,869	3,724	3,653	3,540	3,514	4,384	4,142	38,151	3,179
640	3,890	3,827	2,786	2,387	2,903	2,909	2,548	3,866	2,992	2,710	3,318	3,903	4,346	42,385	3,260
641	4,811	5,098	3,237	3,841	4,652	5,409	4,265	5,081	3,900	4,473	5,152	4,293	4,639	58,851	4,527
710	3,226	2,615	2,611	2,173	3,375	932	-	1,989	1,885	1,207	1,095	2,737	2,499	26,344	2,195
711	-	-	-	-	-	-	-	-	505		1,233	3,188	2,296	7,222	1,806
712	1,892	672	1,641	521	1,727	2,979	1,501	2,038	1,231	801	1,439	1,659	1,148	19,249	1,481
Diesel average	3,037	4,463	2,637	3,089	3,687	3,933	3,227	4,224	3,515	3,574	3,995	4,193	4,376	47,950	3,688

Table 25 Trial results – monthly ticket revenue ($)

Bus	Oct 17	Nov 17	Dec 17	Jan 18	Feb 18	Mar 18	Apr 18	May 18	Jun 18	Jul 18	Aug 18	Sep 18	Oct 18	Trial total	Trial average month
639	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
640	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
641	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
710	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
711	-	-	-	-	-	-	-	-	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
712	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Average of all buses	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Average per VKT	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	

The three diesel buses (Bus 639, Bus 640 and Bus 641) have covered greater distances than the electric (Bus 710) and hybrid (Bus 712) buses during the trial. This is reflected by the diesel average vehicle kilometres travelled (VKT) of 6,342 km per month, compared to the electric and hybrid bus monthly averages of 3,271[4] and 2,253 VKT, respectively. Distance travelled is a useful metric showing reliability, availability and capability of technology. The comparatively low VKT of the electric and hybrid bus types may in part be due to the routes assigned to each bus, but mainly as a result of the reliability of both the electric and hybrid buses. As a result the diesel buses also carried more passengers. The limited carrying capacity of the electric buses may also have been a factor in this result.

Bus 641 has the highest monthly average ticket revenue and boardings of the diesel buses (and all buses) during the trial. This is supported by the fact it has also travelled the furthest distance which aligns with its slightly higher service costs – see Table 26.

The buses' monthly ticket revenues are highly correlated to the VKT, averaging [redacted] per km across all buses. There is some variance in revenue per VKT between buses, largely due to variance in passenger capacity and fare, for example school routes would generate more concession fares. Despite this it is expected that revenue per VKT of each bus would equalise over time as further data is collected. That is, it is not expected that bus type influences rider behaviour, thus the average fare of [redacted] per VKT has been used in the modelling for all buses.

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[4] Excludes bus 711

Table 26 Trial results – monthly service cost ($)

Bus	Oct 17	Nov 17	Dec 17	Jan 18	Feb 18	Mar 18	Apr 18	May 18	Jun 18	Jul 18	Aug 18	Sep 18	Oct 18	Trial total	Trial average month
639	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
640	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
641	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
710	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
711	-	-	-	-	-	-	-	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
712	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Diesel average	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Each bus has incurred servicing costs almost every month in which it has operated. The diesel buses, on average, have very similar average monthly costs. The electric buses have slightly lower costs on average – approximately half the service cost per month. However, per VKT the buses are similar; the average diesel bus incurs $0.18 (18.35 cents) of service costs per VKT, essentially equal to the electric bus which incurs $0.18 (18.15 cents) of service costs per VKT. The hybrid bus had the highest average service cost during the trial at $0.34 (34.40 cents) per VKT.

Table 27 Trial results – average fuel (diesel or electricity) use per 100 kilometres ($)

Bus	Oct 17	Nov 17	Dec 17	Jan 18	Feb 18	Mar 18	Apr 18	May 18	Jun 18	Jul 18	Aug 18	Sep 18	Oct 18	Trial total	Trial average month
639 (L per 100km)	35	209	36	35	37	35	34	34	32	32	32	33	33	407	34
640 (L per 100km)	35	36	36	35	35	33	32	31	31	31	32	32	34	431	33
641 (L per 100km)	49	47	47	42	51	46	44	43	47	34	34	34	33	553	43
710 (KWh per 100km)	70	83	84	83	83	82	-	88	90	101	86	78	83	1012	84
712 (L per 100km)	26	29	29	29	28	28	28	27	29	30	30	30	30	371	29
Diesel average (L per 100km)	40	97	39	37	41	38	37	36	37	32	33	33	33	477	37

Fuel usage data per 100 VKT between October 2017 and October 2018 is shown for all buses in Table 27.

Of the diesel buses, Bus 641 has exhibited the highest fuel consumption per VKT, particularly prior to July 2018, after which its fuel consumption reduced to be approximately in-line with Bus 639 and Bus 640. Possible reasons for the higher fuel usage for Bus 641 could be it spends more time driving a stop-start route or during peak times when there is greater congestion. Note that the November 2017 usage value for Bus 639 has been excluded from the average calculation as this was deemed an outlier (possibly from a data error or driver behaviour) and would distort the trial data and appraisal outcomes.

The electric and hybrid buses have similar levels of consistency in terms of fuel efficiency; within ±20% of their respective averages.

Given fuel use per 100km is a scalable cost parameter in that it is multiplied with VKT to obtain total fuel usage, there was a case to use the median value instead of average to best reflect typical performance. However, for sake of consistency the average was adopted, with removal of outliers such as the November 2017 usage value for Bus 639.

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Table 28 Trial results – missed peaks (average number per month)

Bus	Oct 17	Nov 17	Dec 17	Jan 18	Feb 18	Mar 18	Apr 18	May 18	Jun 18	Jul 18	Aug 18	Sep 18	Oct 18	Trial total	Trial average month
639	0	0	0	0	1	0	0	1	0	0	2	0	1	5.0	0.4
640	3	1	0	1	0	2	0	0	2	2	1	0	1	13.0	1.0
641	0	1	0	0	0	1	0	1	2	2	0	2	3	12.0	0.9
710	2	7	4	6	7	17	38	16	13	13	32	18	1	174.0	13.4
711	-	-	-	-	-	-	-	-	32	32	32	4	0	100.0	20.0
712	1	7	4	2	18	5	0	4	1	1	1	12	2	58.0	4.5
Diesel average	1	0.67	0	0.33	0.33	1	0	0.67	1.33	1.33	1	0.67	1.67	10.0	0.8

Table 28 contains the missed peak data of each bus during the trial period. This reflects the reliability of each bus to meet commuter demand.

The diesel buses have been significantly more reliable than the electric and hybrid buses to date during the trial period. The electric bus suffered from overweight issues, suspension and brake issues as the primary reasons for missed peaks from March through to the start of September. It is not clear if part of this unreliability is more attributable to 'growing pains' associated with initial uptake of the vehicle types or whether these problems would persist indefinitely. Further investigation is recommended.

It should be noted that missed peaks data has not been used or reflected in the economic appraisal. This is because the appraisal is based on direct and average costs; for example, a missed peak would be reflected by fewer VKT and reduced ticket revenue. However, the comparatively higher importance of a bus service in the morning peak compared with a midday service is not captured in the appraisal.

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6.2 Projections

This section predicts the financial and economic performance of each bus type based on trial data for the 13-month period between October 2017 and October 2018 and the prescribed 20-year asset life of each bus.

6.2.1 Financial and Economic Value

The financial and economic performance of each bus type are shown in Table 29. These values are based on data collected during the trial. The economic performance has been termed 'whole of life cost' in the table – this figure is the present value of revenue less the present value of costs.

Table 29 Economic performance of each bus at 7% discount rate

Parameter	Diesel	Hybrid	Electric
PV revenue ($)	**587,284**	**208,623**	**302,923**
Vehicle purchase cost ($)	463,901	557,216	695,000
Supporting infrastructure cost ($)	50	50	2,130
PV CAPEX ($)	**463,951**	**557,266**	**697,130**
PV routine service & maintenance costs ($)	147,976	98,507	75,469
PV of major service costs ($)	36,640	49,777	135,289
PV fuel costs ($)	346,436	95,611	45,696
PV OPEX ($)	**531,051**	**243,895**	**256,454**
Whole of life cost (financial) ($)	**407,718**	**592,538**	**650,661**
PV external costs ($)	705,603	211,256	113,028
Whole of life cost (economic) ($)	**1,113,321**	**803,794**	**763,688**

The electric bus requires greater capital investment and has a larger whole of life financial cost than the diesel bus. The hybrid bus requires less capital than the electric bus but more than the diesel bus; however, it has the lowest present value of OPEX due primarily to it having the lowest VKT during the trial period. This is also the reason why it has the lowest present value of revenue of all bus types. The financial analysis shows that the performance of the buses is closely linked to VKT.

The diesel bus performs better financially than the electric and hybrid buses as reflected by the net whole of life costs, due primarily to a lower capital cost than the electric and hybrid bus types and similar net operating positions, as shown in Figure 17. Note the increases in cumulative whole of life cost some years are due to major servicing requiring replacement parts for the respective buses – refer to the stated assumptions in Section 3.2.4 for further detail.

While the analysis indicates that diesel buses have a greater financial whole of life cost than the electric and hybrid buses (albeit all are net costs), the hybrid and electric buses perform better economically when taking external costs into consideration. The electric bus will have a lower whole of life cost than the diesel bus from 2024 onwards, while the hybrid will have a lower whole of life cost from 2022, as shown in Figure 18.

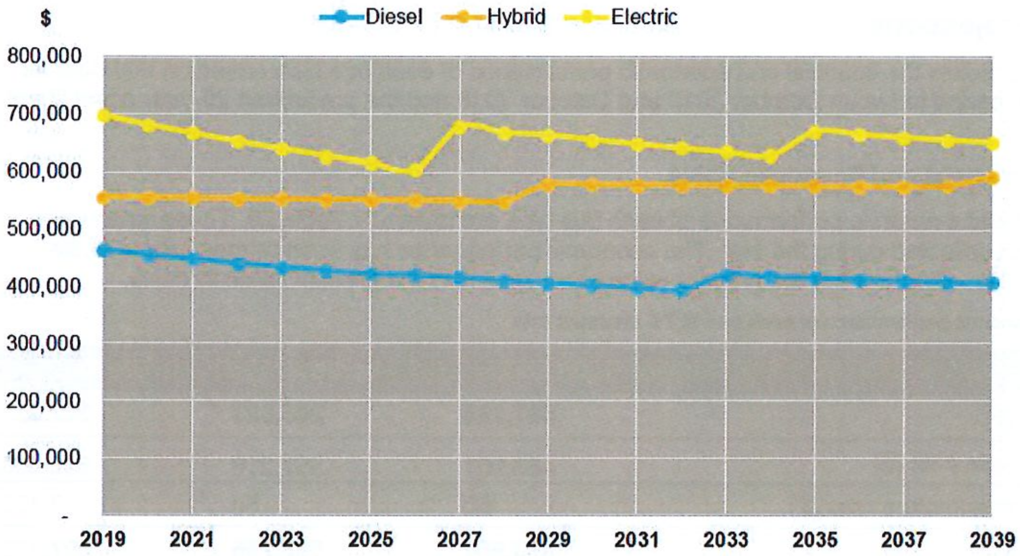


Figure 17 Financial cumulative cost of each bus over time

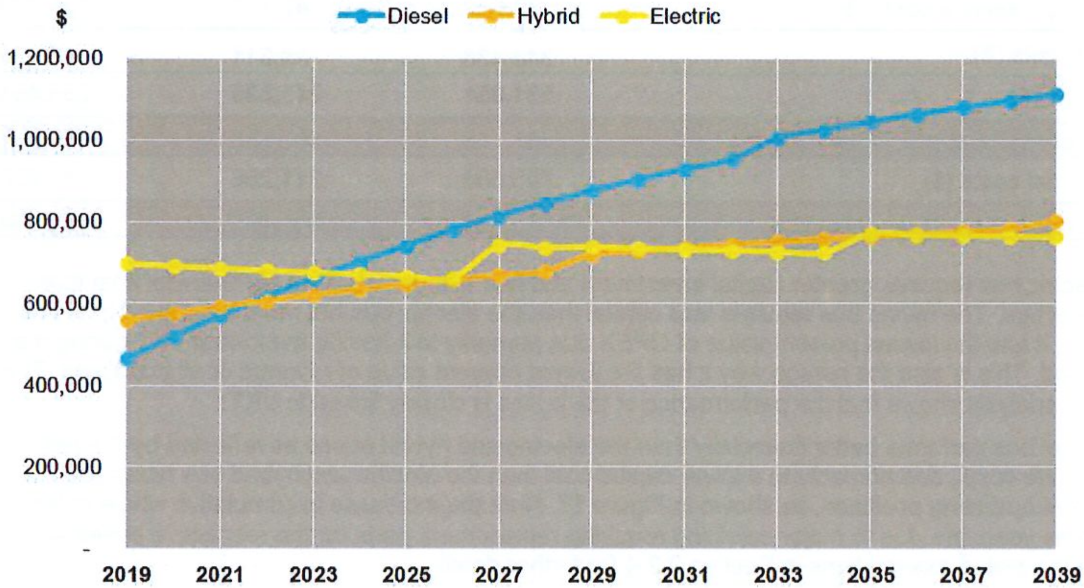


Figure 18 Economic cumulative cost of each bus over time

The comparative performance of the electric bus compared with both the hybrid and diesel buses is expected to improve with an increase in VKT (for all buses) due to lower running costs, maintenance costs and environmental costs than its diesel-consuming counterparts. Financial and economic performance would improve for all buses if there was greater patronage and other income streams such as advertising revenue were included in the appraisal.

The economic performance of each bus would further improve if the appraisal included other non-monetised benefits such as amenity value[5] and option value[6].

[5] Amenity value refers to the characteristics that enhance people's appreciation of an area. The electric bus would likely provide more amenity than the diesel bus.
[6] Option value refers to willingness to pay for maintaining a public asset or service so that the individual has the option to benefit from the asset or service, even if they are unlikely to use it.

When comparing the performance of each bus, it is important to recall that the hybrid bus incurred the largest service costs per VKT which has impacted both its financial and economic performance, a potential short-coming of trialling only one bus. Given the hybrid bus has both diesel and electric engine components this could perhaps be expected, however the magnitude to which this difference is reasonably expected is worth further consideration. Note also that many of the costs of Bus 711 were excluded from the analysis due to it being unavailable prior to June 2018 (over half the trial period) – the reasons behind the prolonged unavailability of Bus 711 should also be considered regarding procurement in future.

6.2.2 Performance based on normalised VKT

To illustrate the performance of each bus type under a modelling scenario whereby they all perform equal work (equal VKT), the financial and economic whole of life costs for each bus type are presented in Table 30. These results are based on the same trial data except each bus travels the average VKT of 63,000 km/year.

Table 30 Economic performance of each bus at 7% discount rate, using normalised VKT

Parameter	Diesel	Hybrid	Electric
PV revenue ($)	**486,139**	**486,139**	**486,139**
Vehicle purchase cost ($)	463,901	557,216	695,000
Supporting infrastructure cost ($)	50	50	2,130
PV CAPEX ($)	**463,951**	**557,266**	**697,130**
PV routine service & maintenance costs ($)	122,491	229,543	121,115
PV of major service costs ($)	31,207	73,724	140,225
PV fuel costs ($)	286,770	222,795	73,334
PV OPEX ($)	**440,468**	**526,063**	**334,674**
Whole of life cost (financial) ($)	**418,280**	**597,190**	**545,665**
PV external costs ($)	584,080	492,273	181,390
Whole of life cost (economic) ($)	**1,002,361**	**1,089,463**	**727,055**

Normalising the VKT improves the relative financial performance of the electric bus, as shown in Figure 19. This is due to it having the lowest fuel and service costs per VKT. The lower fuel cost of the hybrid relative to the diesel is offset by its higher servicing costs per VKT; based on the trial data.

The relative improvement in performance (reduction in whole of life cost) of the diesel bus under the normalised VKT modelling compared to the trial data modelling is because all buses have a negative operating margin (net revenue per VKT) and the diesel bus has a decrease in VKT while the electric has an increase in VKT. If all buses were to increase VKT, the performance of the electric bus would comparatively improve (see sensitivity test 8). This is affirmed by the divergence in the electric bus curve (relatively flat) and diesel bus curve (sloping up) in Figure 20.

Figure 19 Financial cumulative cost of each bus over time

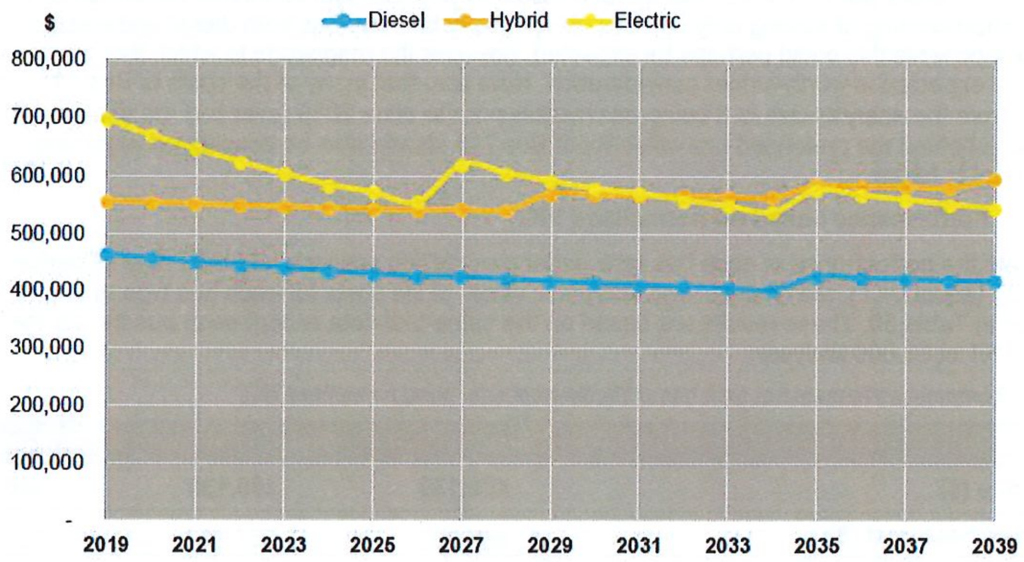
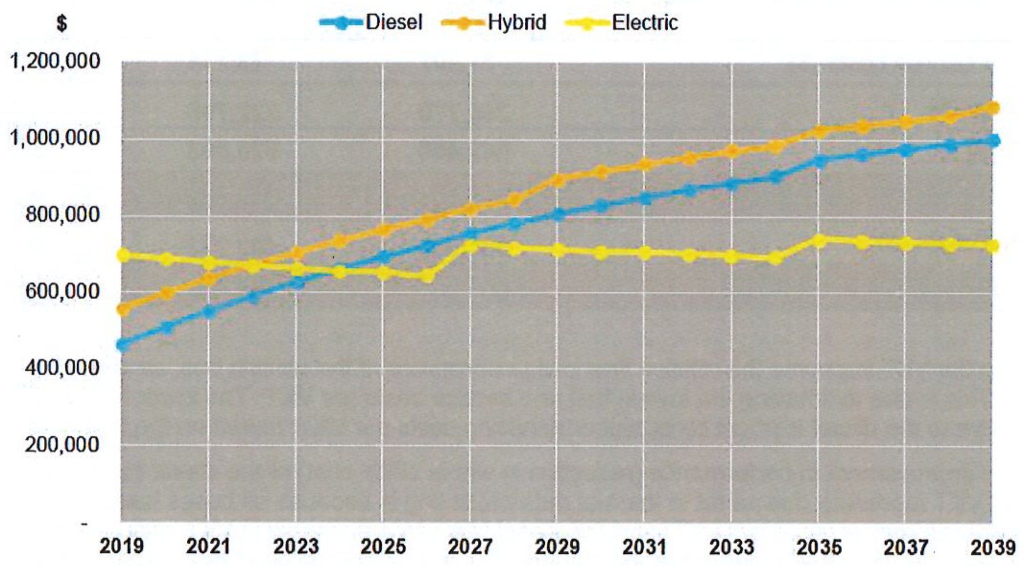


Figure 20 Economic cumulative cost of each bus over time



6.2.3 Interpretation of results

This analysis is based on a single bus, however ability to meet the operational expectations of Transport Canberra and City Services' bus fleet (capacity/passenger potential and reliability) must be considered in tandem with these results. Based on the more favourable economic results of the battery electric bus type, a sensible approach to the uptake of these buses in Canberra is recommended. This could be likened to the advised uptake of renewable energy in general: a stable and reliable base is required to ensure service expectations are met during the transition toward the more environmentally friendly but currently less reliable alternative. The 'advisable' rate of uptake would require further investigation and reassessing over time.

6.3 Sensitivity analysis

Sensitivity testing was undertaken to show the effect on the indicative viability of each bus type by varying key input values that could change during the appraisal period. This process demonstrates the robustness of the economic modelling and highlights the following:

- Elasticity of inputs (degree to which a change in an input will influence a change in the output)
- Upper and lower bounds of expected viability – highlighted by the 'favours diesel' and 'favours electric' scenarios.

The scenarios tested at a seven percent discount rate are shown in Table 31. 'WLC' denotes whole of life cost.

Table 31 Sensitivity tests: effect of uncertainties on economic net present value at 7% discount rate

Sensitivity tests at 7% discount rate	Diesel WLC ($)	Hybrid WLC ($)	Electric WLC ($)
1. CAPEX - test at 80%	909,571	978,010	587,629
2. Electricity price - test at 150%	1,002,361	1,089,463	763,722
3. Electricity price - test at 50%	1,002,361	1,089,463	690,388
4. Diesel price - test at 150%	1,145,746	1,200,861	727,055
5. Diesel price - test at 80%	945,007	1,044,904	727,055
6. Battery cost - test at 80%	1,001,918	1,079,819	700,831
7. Revenue - test at 120%	905,133	992,236	629,827
8. VKT - test all buses at diesel bus km (85K)	1,044,040	1,113,267	684,150
9. Service cost - test at 150%	1,063,606	1,204,235	787,612
10. Favours diesel (2,5)	**945,007**	**1,044,904**	**763,722**
11. Favours electric (1,3,4,6,8)	**1,052,513**	**1,079,763**	**524,738**

Sensitivity testing for each type of bus results in net whole of life costs under all scenarios at a seven percent discount rate, indicating the operating revenues are insufficient to recover capital investment and offset environmental externalities. Due primarily to the impact of environmental externalities, the electric and hybrid buses perform better than the diesel bus under all scenarios.

Notably under test number eight; 'VKT – test all buses at diesel bus km' the electric bus performs the best of all bus types. More interestingly, by comparison with the economic whole of life costs in Table 29, the economic whole of life cost of the electric bus is the only to improve with an increase in VKT. The economic performance of the hybrid worsens indicating its net benefits are unable to recoup its net economic costs. This is affirmed by the 'favours electric' scenario illustrated in Figure 22 overleaf.

Figure 21 shows the 'favours diesel' test (whereby the cost of electricity is increased by 50 percent and diesel is 20 percent cheaper at $0.94/L). It highlights that the electric bus has a whole of life cost of $763,722 at the end of the appraisal period, compared to the hybrid bus with a whole of life cost of $1,044,904 and diesel bus which has a whole of life cost of $945,007.

By contrast, under the 'favours electric' scenario (Figure 22, whereby CAPEX of each bus reduces by 20 percent, electricity prices and electric batteries both reduce by 20 percent, diesel prices increase by 50 percent and all buses do the same VKT of 85,000 km/year), the electric bus has the lowest economic whole of life cost at $524,738, while the diesel bus has a whole of life cost of $1,052,513, over $500,000 worse per bus. The hybrid performs slightly worse than the diesel with a whole of life cost of $1,079,763.

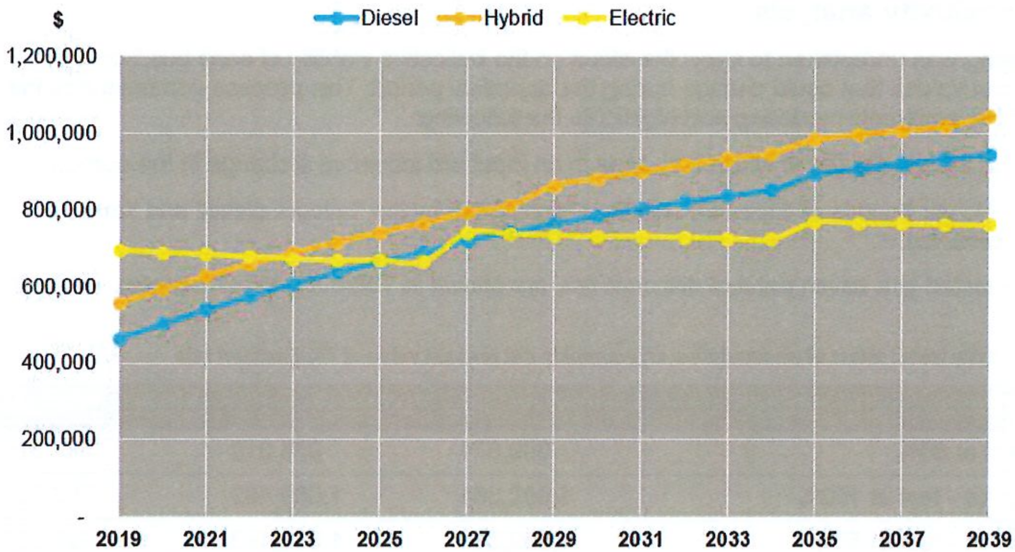


Figure 21 Economic cumulative cost of each bus over time under the 'favours diesel' sensitivity test at 7% discount rate

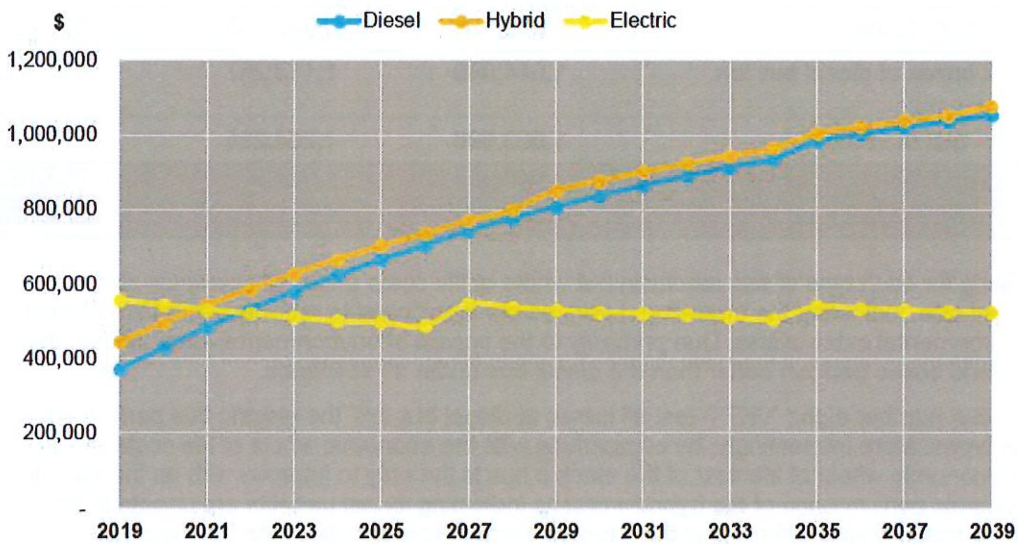


Figure 22 Economic cumulative cost of each bus over time under the 'favours electric' sensitivity test at 7% discount rate

The sensitivity scenarios tested at a ten percent discount rate are shown in Table 32.

Table 32 Sensitivity tests: effect of uncertainties on economic net present value at 10% discount rate

Sensitivity tests at 10% discount rate	Diesel WLC ($)	Hybrid WLC($)	Electric WLC ($)
1. CAPEX - test at 80%	799,671	864,963	573,841
2. Electricity price - test at 150%	892,462	976,416	742,733
3. Electricity price - test at 50%	892,462	976,416	683,800
4. Diesel price - test at 150%	1,007,689	1,065,937	713,267
5. Diesel price - test at 80%	846,371	940,607	713,267
6. Battery cost - test at 80%	892,111	969,655	693,760
7. Revenue - test at 120%	814,328	898,282	635,132
8. VKT - test all buses at diesel bus km (85K)	994,701	976,416	706,025
9. Service cost - test at 150%	941,680	1,068,649	761,932
10. Favours diesel (2,5)	**846,371**	**940,607**	**742,733**
11. Favours electric (1,3,4,6,8)	**914,548**	**947,723**	**524,867**

Sensitivity testing at a 10 percent discount rates generates similar outcomes; the electric bus is generally the preferred bus types under most tests, except for Test 2, Test 5 and Test 10 (comprised of Test 2 and Test 5) under which the diesel bus is the preferred bus type. However, all buses generate negative economic outcomes under all scenarios. This reiterates that operating revenues are insufficient based on the trial data and assumptions used in this appraisal.

The cumulative economic whole of life cost of each bus over time under the 'favours diesel' and 'favours electric' scenarios is illustrated in Figure 23 and Figure 24.

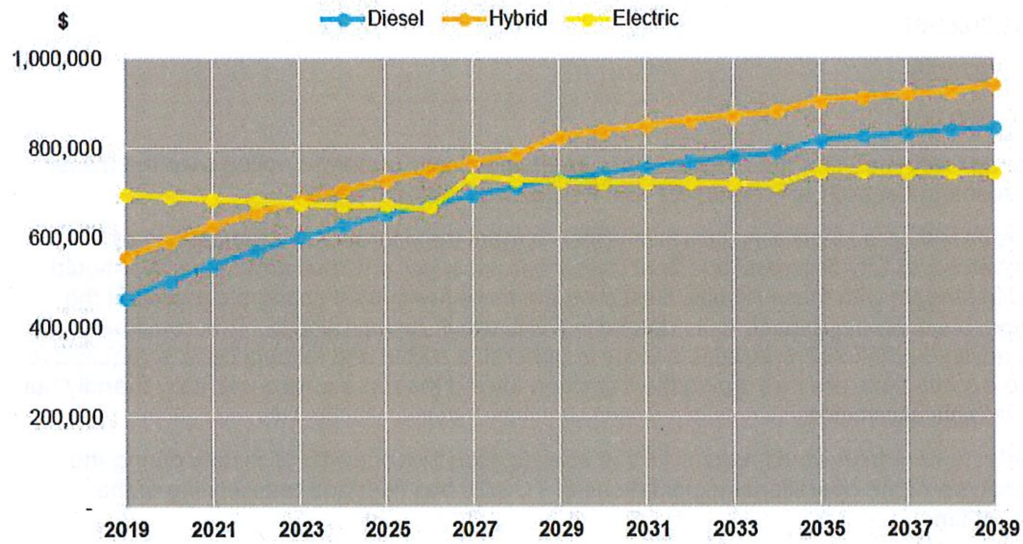


Figure 23 Economic cumulative cost of each bus over time under the 'favours diesel' sensitivity test at 10% discount rate

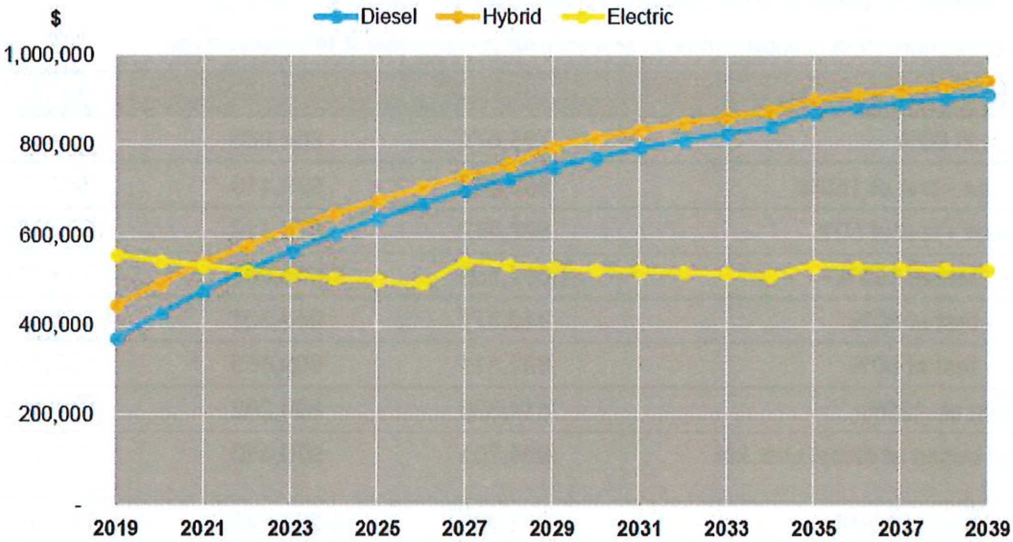


Figure 24 Economic cumulative cost of each bus over time under the 'favours electric' sensitivity test at 10% discount rate

6.4 Conclusions

The financial and economic performance of an electric, hybrid and diesel bus(es) have been appraised based on the recorded trial data in Section 6.1 and the assumptions listed in Section 3.2.4. The financial and economic WLC's of each bus are subject to change based on future trial data.

The diesel bus performs best financially, due primarily to a lower capital cost. However, the electric bus performs best economically followed by the diesel bus when normalising VKT and considering external costs. The economic whole of life cost of each bus is:

- Diesel: $1,002,361
- Electric: $727,055
- Hybrid: $1,089,463.

Sensitivity testing reaffirmed that the electric bus is an economically preferred option over the diesel bus under all scenarios at both seven percent and ten percent discount rates.

This analysis is based on a single bus, however ability to meet the operational expectations of Transport Canberra and City Services' bus fleet (capacity/passenger potential and reliability) should be considered in tandem with these results. Based on the more favourable economic results of the electric bus type, a sensible approach to its uptake in Canberra is recommended. This could be likened to the advised uptake of renewable energy in general: a stable and reliable base is required to ensure service expectations are met during the transition toward the more environmentally friendly but currently less reliable alternative.

The 'advisable' rate of uptake would require further investigation into operational issues during the trial, deeper analysis of the operational expectations of TCCS's bus fleet and reassessing of the advised rate over time.

7.0 Conclusions

An overall comparison of the various criteria used in this assessment is summarised in Table 33. Diesel buses generally perform best in relation to daily operation and financial cost, while electric buses perform best in relation to environmental emissions and energy efficiency. The performance of Hybrid buses generally falls between the diesel and electric bus for all criteria.

It shows a number of other criteria which favour diesel and electric buses. These are discussed under separate headers for operational, environmental and economic benefits below.

Table 33 Summary comparison

Criterion		Diesel Euro VI	Electric	Hybrid Euro V
Operational	Passenger capacity	68 (48 seated)	49 – 55 (35 seated)	68 (44 seated)
	Fuel cost efficiency[2]	$26,498/year	$3,857/year	$19,391/year
	Fuel energy efficiency[2]	938.4 GJ/year	179.6 GJ/year	686.6 GJ/year
	Unscheduled missed peaks	0.8% peaks/bus	35.7% peaks/bus	14.2% peaks/bus
	Acceleration	0-40 km/h 8 s 0-60 km/h 14 s 0-80 km/h 23 s	0-40 km/h 6 s 0-60 km/h 14 s 0-80 km/h 22 s	0-40 km/h 11 s 0-60 km/h 22 s 0-80 km/h 33 s
	Range	810 km	450 km	760 km
	Turning circle	18.6 m	21.5 m	19.6 m
	Refuelling time	6 min	6 h	6 min
Environmental	GHG (CO_2) emissions[2]	62.7 t/year	1.6 t/year	51.1 t/year
	PM10 emissions[2]	4.9 kg/year	4.6 kg/year	7.1 kg/year
	NO_x emissions[2]	28.6 kg/year	0 kg/year	41.5 kg/year
	Internal noise (at 50 km/h)	58 – 61 dB (A) from front to rear	66.5 – 68 dB (A) from front to rear	66 – 68 dB (A) from front to rear
	Internal noise (stationary)	49 – 58 dB (A) from front to rear	Same as background, as no engine noise	
	External noise (drive by)	79.9 dB (A)	77.7 dB (A)	75.7 dB (A)
	External noise (compressor & brake)	66.6 dB (A)	69.6 dB (A)	70.6 dB (A)
Economic	Capital cost[4]	[redacted]	[redacted]	[redacted]
	Supporting infrastructure	$50/bus	$2,130/bus	$50/bus
	Routine service & maintenance costs	$11,340/year	$11,340/year	$21,420/year
	External costs[2]	$55,540/year	$16,380/year	$55,540/year
	Whole of life financial cost[2]	$418,280	$545,665	$597,190
	Whole of life economic cost[2]	$1,002,361	$727,055	$1,089,463

Note: 1. Cells highlighted in green show the bus type with the best result for each criterion.

2. Based on a typical ACTION bus travelling 63,000 km per year.

3. External costs are costs associated with environmental externalities, including air pollution, GHG emissions, noise, water pollution, urban separation and upstream and downstream effects as described in Table 11.

4. Capital cost excludes ticketing systems, radio systems, commissioning expenses and other associated costs.

Operational Benefits

The operational assessment reflected feedback from various technical data collection and responses from driver and passenger surveys. It clearly indicated that the diesel buses performed better than electric or hybrid buses in relation to all operational criteria, other than fuel efficiency.

In terms of operational capability the diesel bus performed best against most of the performance criteria used in the benchmark tests, with key strengths being internal noise at 50 km/h, seating capacity and turning circle. Driver surveys also showed a preference for diesel buses rather than electric or hybrid buses. This is because the diesel buses are considered more reliable, quieter and easier to drive, having better acceleration and braking. Acceleration was highlighted as a weakness of hybrid buses during benchmark tests, but braking of all buses was considered satisfactory.

Drivers would consider electric buses if the technology improved in terms of reliability and acceleration. However, the hybrid was not recommended by drivers to be introduced into the Transport Canberra bus fleet.

The main factor limiting the operation of electric buses was their exceedance of legal weight restrictions under the Road Transport (Mass, Dimensions and Loading) Regulation 2010. This resulted in the electric buses being off the road for seven weeks or more whilst Transport Canberra obtained a temporary permit for them to operate on Canberra roads. It is a major obstacle for their future use and integration with existing options, but may be overcome by future technological improvements.

In terms of operational reliability the diesel buses performed much better than the electric or hybrid buses, with fewer unscheduled breakdowns for all months of the trial. The electric buses proved to be the most unreliable of the three bus types during the trial. They were off the road more than other buses, not just because of the weight issue but also missed peak services due to unscheduled breakdowns and servicing requirements. The majority of these missed peaks were due to brake and suspension issues; not due to battery system performance (other than weight), but was due to other build quality issues. Once resolved these may not be a recurring issue and may over represent the apparent unreliability of the electric buses. Better build quality and more local supplier familiarity with the electric vehicle and spare parts could also reduce downtime and improve reliability in future.

The driver surveys indicated driver concerns and uncertainty regarding the reliability of electric buses, including available driving range. However, on-board monitoring of electric buses indicated that the state of charge was generally higher than 20% at the end of a daily duty cycle, but did show high variability.

During the trial battery charging times were not considered a factor as the two buses were easily scheduled to accommodate recharging. It is when there are significant numbers of electric buses at a depot and having to schedule enough time for recharging or managing buses that need to do double shifts with minimum turnaround time that recharging time could become an issue.

The diesel and hybrid buses have a longer driving range than the electric bus, but all buses exceed the current maximum trip length undertaken by buses in the Transport Canberra fleet (about 350 km). That is, the trial buses were able to perform a day's work without the need to refuel or recharge and therefore the range of each of the trial buses was not a performance factor. However in the case of the electric buses the weight penalty of the carried battery banks to enable that range greatly affected the passenger carrying capacity.

In each month of the trial the diesel buses consistently travelled a greater distance than the electric or hybrid buses. This may in part be due to the routes assigned to each bus, but mainly as a result of the reliability of both the electric and hybrid buses. As a result the diesel buses also carried more passengers. The limited carrying capacity of the electric buses may also have been a factor in this result.

In terms of operational capacity the diesel buses performed much better than the electric or hybrid buses. The electric buses have a serious deficiency in relation to passenger capacity. Due to its tare weight the first electric bus was able to carry up to 55 passengers in total, 35 of them seated. The second electric bus was even heavier limiting its capacity to 49 passengers in total. In comparison the diesel and hybrid buses can carry up to 68 passengers in total. This limitation may be a factor in the relatively low passengers numbers carried by the electric buses during the trial.

In terms of operational efficiency the electric buses performed best, both in terms of dollars and kJ per passenger kilometre. This is also reflected in the environmental benefits.

Passenger surveys on electric and hybrid buses indicated that the performance of these buses in relation to noise, smell and smoothness of travel was satisfactory. The responses were more positive for the electric buses than the hybrid buses.

Environmental Benefits

The following conclusions follow from the environmental assessment undertaken for this trial:

- With the exception of October 2017, the diesel bus travelled the most total kilometres each month and therefore emitted the most greenhouse gases, PM10 and NO_x emissions each month throughout the trial period.
- The electric bus would produce much less GHG emissions than diesel or hybrid buses.
- With the exception of August 2018, the diesel bus emitted the most greenhouse gases per passenger-kilometre each month throughout the trial period.
- Taking into account the distance and number of passengers carried, there is not a significant difference between the amount greenhouse gases produced by the diesel bus and hybrid bus per passenger-kilometre.
- The hybrid bus produced the most PM10 emissions per passenger kilometre for ten months out of the 12-month trial period. This can be attributed to the Euro V engine used in the hybrid bus compared with the Euro VI engine used in the diesel bus.
- The majority of PM10 emissions are produced from the brakes and tyres, rather than from the exhaust.
- The hybrid bus produced the most NO_x emissions per passenger kilometre for nine months out of the 12-month trial period. This can be attributed to the Euro V engine used in the hybrid bus compared with the Euro VI engine used in the diesel bus.
- The diesel bus was the quietest bus internally at 50 km/h and externally at the compressor and brake. The hybrid and electric bus were the quietest buses while stationary internally and externally (drive by).

Overall, switching from a diesel bus to a hybrid or electric bus would contribute to the reduction in greenhouse gas emissions targets outlined in the *Climate Change and Greenhouse Gas Reduction Act 2010* and the AP2. A hybrid vehicle is not considered to be a zero emissions vehicle as it uses an engine powered solely by petrol, diesel or LPG with an electric motor and battery recovering deceleration energy and boosting efficiency.

In terms of PM10 and NOx emissions however, the diesel bus proved to be more efficient overall than the hybrid bus based on the Euro VI standard engine used in the diesel bus compared with the Euro V standard engine used in the hybrid bus. There would have to be a fuel efficiency of over 80% for the difference in the Euro standards to be negated.

Economic and Financial Benefits

The diesel bus performs best financially, due primarily to a lower capital cost. However, the electric bus performs best economically followed by the hybrid bus when considering external costs. The economic whole of life cost of each bus is:

- Diesel: $1,002,361
- Electric: $727,055
- Hybrid: $1,089,463.

Sensitivity testing reaffirmed that the electric bus is an economically preferred option over the diesel bus under all scenarios at both seven percent and ten percent discount rates.

This analysis is based on a single bus, however the ability to meet the operational expectations of Transport Canberra's bus fleet (capacity/passenger potential and reliability) should be considered in tandem with these results. Based on the more favourable external economic results of the electric bus type, future consideration of the uptake of electric buses in Canberra is recommended. This could be likened to the advised uptake of renewable energy in general: a stable and reliable base is required to ensure service expectations are met during the transition toward the more environmentally friendly but currently less reliable alternative.

The 'advisable' rate of uptake of electric buses will depend on new or alternative technology which results in vehicles with:

- Lower axle weight
- Lighter and more reliable batteries with increased battery life
- Increased seating and overall passenger carrying capacity
- Lower capital costs.

Key issues of the maintenance issues of the electric vehicle should be considered in any specification or procurement to minimise the risk likelihood of similar down time issues once they are introduced into the fleet.

The hybrid (Euro V) bus tested in this trial is not suitable either, as drivers considered that it was not a pleasant bus to drive, having slow acceleration and being rough to drive. Also it cannot achieve zero emissions.

8.0 References

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Beer (2002) *Valuation of Pollutants Emitted by Road transport into the Australian Atmosphere*

Department of Environment and Energy (2018) *National Greenhouse Accounts Factors, Australian National Greenhouse Accounts,* Available online at http://www.environment.gov.au/system/files/resources/80f603e7-175b-4f97-8a9b-2d207f46594a/files/national-greenhouse-accounts-factors-july-2018.pdf, accessed 10 December 2018.

Transport for New South Wales (2016) *Principles and Guidelines: Economic Appraisal of Transport Investments and Initiatives*

ACT Government (2017) Past and projected future components of electricity supply to the ACT, and resultant emissions intensity, Available online at

https://www.environment.act.gov.au/__data/assets/pdf_file/0011/1088912/2017-ACT-elec-Report-final.pdf

Appendix A

Benchmark Test Results

Appendix A Benchmark Test Results

Standard benchmark acceptance tests have been undertaken for each of the trial buses. A summary comparison of the performance specifications of each of the buses where some differences were observed is given in Table 34. There were no apparent differences in the water test, uphill start test and brake performance. The bus that performed best for each test is highlighted in green.

Table 34 Comparison of bus specifications

Performance Criterion	Diesel	Electric[1]	Hybrid
Model	Scania Rigid Euro 6	Carbridge Toro Electric Rigid	Volvo Hybrid Rigid
Heating	• Temperature control set at 22 C • Slightly more than 1 C per minute heating • Temperature difference varied more than 1 C from front to rear (19.2 – 21.0 C), but less than 22 C	• Temperature control set at 22 C • Slightly more than 1 C per minute heating • Temperature difference varied more than 1 C from front to rear (close to 22 C)	• Temperature control set at 18 C • About 0.5 C per minute heating achieved • Temperature difference of more than 1 C from front to rear
Air conditioning	• Temperature control set at 22 C • Slightly more than 1 C per minute cooling • Temperature difference varied less than 1 C from front to rear (19.3 – 19.9 C) , but less than 22 C	• Temperature control set at 22 C • Temperature automatically controlled, so no performance test for air conditioning	• Temperature control set at 18 C • Temperature automatically controlled, so no performance test for air conditioning
Internal noise (at 50 km/h)	• 58 – 61 dB (A) from front to rear	• 66.5 – 68 dB (A) from front to rear	• 66 – 68 dB (A) from front to rear
Internal noise (stationary)	• 49 – 58 dB (A) from front to rear	• Same as background, as no engine noise	• Same as background, as no engine noise
External noise (drive-by)	• 79.9 dB (A) (less than allowable of 80 dB (A)	• 77.7 dB (A)	• 75.7 dB (A)
External noise (compressor and brake)	• 66.6 dB (A) (less than allowable of 72 dB (A)	• 69.6 dB (A)	• 70.6 dB (A)
Top speed test	• Top speed of 85 km/h reached easily	• Top speed of 80 km/h reached	• Top speed of 80 km/h reached easily
Acceleration test	• 0-40 km/h 8 s 0-60 km/h 14 s 0-80 km/h 23 s	• 0-40 km/h 6 s 0-60 km/h 14 s 0-80 km/h 22 s	• 0-40 km/h 11 s 0-60 km/h 22 s 0-80 km/h 33 s
Hill climb test (not less than 75 km/h in 55 s)	• Top speed of 81 km/h reached in 41 s	• Top speed of 75 km/h reached in 41 s	• Top speed of 75 km/h reached in 41 s
Turning circle (less than 25 m)	• 18.6 m	• 21.5 m	• 19.6 m

Performance Criterion	Diesel	Electric[1]	Hybrid
Speedo accuracy	• 1.0 – 1.5 km/h higher than actual	• 3 – 4 km/h higher than actual	• 1 – 2 km/h higher than actual
Seating capacity	• 48 seated and 18 standing	• 35 seated and up to 20 standing	• 44 seated and 24 standing

Note: 1. Benchmark data for first electric bus delivered (i.e. BUS 710)

Appendix B

Data for Monthly Reports

Appendix B Data for Monthly Reports

Data collected for each bus in the trial for each month of the project is listed below:

1. Telematics data logger

   includes:

   - Date
   - Vehicle ID
   - Fuel consumption (L/100km)
   - Distance (km)
   - Fuel used (L)
   - CO2 (kg)
   - Driving time (h & %)
   - Standing time (h & %)
   - Idle time (h & %)
   - Average speed

2. Viriciti data logger

   includes:

   - Date
   - Idling time
   - Driving time
   - In Service / in Operation
   - Consumption driving per day (kWh/km)
   - Consumption in service per day (kWh/km)
   - Regeneration rate per day
   - Energy charged per day (kWh)
   - Energy consumed (kWh)
   - Energy driven per day (kWh per day)
   - Energy idled per day (kWh per day)
   - Energy recovered per day (kWh)
   - Energy used per day (kWh)
   - Average speed
   - Average speed in service
   - Distance driven per day
   - CO2 savings (compared to Euro 6 bus)
   - NOx savings (compared to Euro 6 bus)
   - Particles savings (compared to Euro 6 bus).

3. MyWay data

   - Date

- Bus number
- service number (Route code and Service Code)
- stop number
- stop name
- Boardings
- Alightings
- Passengers on Board
- Segment distance
- Actual Arrival time (or scheduled arrival time)
- Total revenue

4. Fuel/energy data
   - Fuel and electricity usage
   - Fuel and electricity cost rates
5. Workshop maintenance and incident data
   - Breakdowns and costs
   - Service records
   - Scheduled and unscheduled maintenance events by time of day (peak/non-peak)

Other qualitative data relating to driver and passenger feedback is to be collected later in 2018.

Appendix C

Tableau Data Analysis

Appendix C Tableau Data Analysis

The key assumptions and processes used in the analysis of data included in Tableau are:

- Passenger-km
  - Passenger-km is obtained using the MyWay data.
  - It is calculated as a product of PAX_ON_BOARD and SEGMENT_DISTANCE for each sequence of the bus trip. The values obtained are then summed to obtain total passenger-km for each day for each bus service.
  - The measure passenger-km is used with fields from other datasets like distance and fuel use. The buses and dates run in the two datasets (Telematics & MyWay) are assumed to match, ignoring differences (if any). A key was generated in both the datasets using the date and vehicle ID and the trips were matched between the two datasets.
- Fuel efficiency
  - To calculate fuel efficiency, the Detailed Trip Data obtained from the Telematics portal is used. The Distance (km) and Fuel Used (Litres) field are used to obtain the total distance travelled and the fuel consumed. For the electric bus, the data obtained from Viriciti portal is used. Toro 001 – Distance and Toro 001 – Energy used, fields are used to obtain the distance travelled and the energy consumed in KWh.
  - Two measures of fuel efficiency are calculated. One as $/km which represents the cost of fuel used for every km travelled by the bus. The second is $/passenger-km which represents the cost of fuel burnt for every km travelled by each passenger who travelled on the bus.
  - The formula used to calculate $/km is

    (Fuel Cost Rate for that month x Fuel Used)/ Distance Travelled.
  - The formula used to calculate $/passenger-km is

    (Fuel Cost Rate for that month x Fuel Used)/ Passenger-km
  - To calculate the fuel efficiency of electric bus, the Retail Energy rates and Network Energy rates obtained from the invoice issued by the energy supplier are used.
  - For the hybrid buses, only the fuel used in litres is used for fuel consumption calculations. External electrical charging (if any) is not considered.
- Reliability
  - The reliability is calculated for two measures – Scheduled and Unscheduled bus services.
- PM 10 emissions
  - Two measures for PM10 emissions are calculated – Total Emission which represent the total emissions released by the buses while in service and Emission per Passenger-km which represents the emissions released by the buses for every km travelled by each passenger.
  - The formula used to calculate the Total Emissions is

    Distance x Emission Factor (0.077 for Diesel Euro VI, 0.03 for Electric)
  - The Emission Factor for hybrid is calculated as follows

    Emission factor of Diesel -(1-(Fuel Use by Hybrid Bus/Fuel Use by Diesel Bus) x 0.044)

    [Note: if hybrid was using Euro VI design standards the latter constant would reduce from 0.044 to 0.004]
  - The formula used to calculate Emissions/Passenger-km is

    Distance x Emission Factor/Passenger-km

- NOx emissions
  - Two measures for NOx emissions are calculated – Total Emission which represent the total emissions released by the buses while in service and Emission per Passenger-km which represents the emissions released by the buses for every km travelled by each passenger.
  - The formula used to calculate the Total Emissions is

    Distance x Emission Factor (0.454 for Diesel Euro VI)
  - The Emission Factor for hybrid bus is calculated as follows

    Emission factor of Diesel x (1-(Fuel Use by Hybrid Bus/Fuel Use by Diesel Bus))
    (3.25 for Diesel Euro V)
  - The formula used to calculate Emissions/Passenger-km is

    Distance x Emission Factor/Passenger-km
- GHG-1 emissions
  - Two measures for GHG-1 emissions are calculated – Total Emission which represent the total emissions released by the buses while in service and Emission per Passenger-km which represents the emissions released by the buses for every km travelled by each passenger.
  - Calculated for diesel and hybrid bus types only.
  - Formula used to calculate Total Emission is

    (Fuel Used x Energy Content Factor x Emission Factor for CH_4/1000) + (Fuel Used x Energy Content Factor x Emission Factor for N_2O/1000) + (Fuel Used x Energy Content Factor x Emission Factor for CO_2/1000) where

    Energy Content Factor = 38.6

    Emission Factor for CH_4 = 0.06

    Emission Factor for CO_2 = 69.9

    Emission Factor for N_2O = 0.5
- GHG-2 emissions
  - Two measures for GHG-1 emissions are calculated – Total Emission which represent the total emissions released by the buses while in service and Emission per Passenger-km which represents the emissions released by the buses for every km travelled by each passenger.
  - Calculated for electric bus type only.
  - Formula used to calculate Total Emission is

    Fuel Used (KWh) x Emission Factor Scope 2/1000
  - Formula used to calculate Total Emission/Passenger-km is

    (Fuel Used (KWh) x Emission Factor Scope 2/1000)/Passenger-km

ACT Government
Transport Canberra and City Services

Freedom of Information – Access Application Form

PRIVACY NOTICE

The personal information you supply on this form will only be used for the purpose of processing your request. Your application must include an email or postal address to which the respondent can send notices under the Act. If all or some of this information is not collected, Transport Canberra and City Services may not be able to communicate with you, inhibiting their obligations under the Act. This could mean the request cannot be dealt with. Your personal information will not be disclosed to a third party without your consent unless statutory obligations require otherwise.

The Transport Canberra and City Services Privacy Policy contains information on how you can access or seek to correct any of your personal information that is held by the Transport Canberra and City Services, as well as the process for lodging a complaint about an alleged breach of the *Information Privacy Act 2014*. The Privacy Policy can be found on the Transport Canberra and City Services website at www.tccs.act.gov.au.

Applicant details	
I wish to make an access application to Transport Canberra and City Services under the *Freedom of Information Act 2016*.	
Name	[redacted]
Address (where notices relating to this request can be sent – either postal or electronic)	
Telephone Contact (Business Hours)	
Telephone Contact (Mobile)	[redacted]
Email Contact	[redacted]

What documents are you requesting under the Act?

- Documents relating to the planning, implementation and status of electric vehicles in the ACT Public Transport Fleet. The information provided on Transport ACT's website does not appear to have been updated since prior to planned rollout of more electric busses in late 2018: https://www.transport.act.gov.au/about-us/public-transport-options/bus/about-the-fleet. Fleet information is acknowledged as in the public interest by ACT Transport's aforementioned website.
- Data on public transport usage in the ACT from the MyWay card system. In particular, usage data comparing daily usage of the Light Rail system and the bus routes it replaced would be appreciated. This data being made accessible would allow greater public accountability of major transport infrastructure projects, and improve public evaluation of these systems they use extensively. Opening this data to Canberra's extensive policy and academic community may also generate valuable discussion nd proposals for future transport network development. According to Transport ACT, this data is already depersonalised and used in planning, so should be readily accessible: https://www.transport.act.gov.au/tickets-and-myway/using-myway/privacy.

Fee Waiver

- If you wish to apply for a fee waiver, the Act sets out a number of provisions to do so:
- The information being requested was previously publicly available but no longer is.
- The information being requested is of special benefit to the public (Ombudsman guidelines see Section 66).
- The applicant is a concession card holder and demonstrates a material connection with the information requested (concession cards include a current health care or pensioner card issued under the Social Security Act 1991; a current pensioner concession card issued in relation to a pension under the Veterans' Entitlements Act 1986 or the Military Rehabilitation and Compensation Act 2004; a current gold card; or a card prescribed by regulation).
- The applicant is a not-for-profit organisation and the application relates to the activities or purposes of the organisation.
- The applicant is a member of the Legislative Assembly.

Transport Canberra and City Services must waive any fees for providing information if the information was not publicly available and the agency makes the information publicly available before or within 3 working days after giving it to the applicant.

Fee waiver application (fill in if applicable. Otherwise leave blank)

☐ I would like to apply for a fee waiver because (state reason/s from the list above).

[provide details and evidence of how this reason applies]

☐ I would like	a copy of these documents sent to the above address **OR** to inspect these document

APPLICANTS SIGNATURE	DATE OF REQUEST
[redacted]	9 September 2019

ACT Government
Transport Canberra and City Services

[redacted]

By Email: [redacted]

Dear [redacted]

Freedom of information request: Reference – 19-091

I refer to your application made under the *Freedom of Information Act 2016* (the FOI Act); and received by Transport Canberra and City Services Directorate (TCCS), on 5 September 2019 in which you sought access to:

1. Documents relating to the planning, implementation and status of electric vehicles in the ACT Public Transport Fleet. The information provided on Transport ACT's website does not appear to have been updated since prior to planned rollout of more electric buses in late 2018.

2. Data on public transport usage in the ACT from the MyWay card system. In particular, usage data comparing daily usage of the Light Rail system and the bus routes it replaced between January and June 2019.

I am an Information Officer appointed by the Director-General under section 18 of the FOI Act to deal with access applications made under Part 5 of the Act.

A response was due to you on 3 October 2019. Thank you for agreeing to extensions to 7 November 2019 to allow time for TCCS to complete your request.

This decision notice relates to part 2 of your request. A separate decision was made on Part 1 of your application on 31 October 2019.

Decision on access

Two data sets were identified as falling within the scope of your request.

The information (or data) captured before July 2019 relating to light rail and bus patronage was not made publicly available. The data has been printed and provided at Attachment A. I have decided to grant full access, under section 50 of the Act, to this document.

Please be advised that patronage data from July 2019 at a weekly aggregate is routinely published and is available on the open data portal at https://www.data.act.gov.au/Transport/Light-Rail-Patronage/kdq8-33q7.

Statement of Reasons
In reaching my access decision, I have taken the following into account:

Factors favouring disclosure (Schedule 2.1)

- (a)(iii) inform the community of the government's operations, including the policies, guidelines and codes of conduct followed by the government in its dealings with members of the community; and
- (a)(xvi) contribute to innovation and the facilitation of research.

Factors favouring nondisclosure (Schedule 2.2)

- No factors in schedule 2.2 were found to be applicable to the information subject to release.

In this instance I have decided that the factors in favour of the release of information, on balance, is paramount and in the public interest.

Online publishing – disclosure log
Under section 28 of the Act, TCCS maintains an online record of access applications called a disclosure log. Your original access application and my decision will be published in the TCCS disclosure log from 3 days after the date of this decision. Your personal details and other personal information will not be published.

You may view TCCS' disclosure log at www.tccs.act.gov.au/about-us/freedom_of_information.

Ombudsman review
My decision on your access request is a reviewable decision as identified in Schedule 3 of the FOI Act. You have the right to seek Ombudsman review of this outcome under section 73 of the FOI Act within 20 working days from the day that my decision is published in the TCCS disclosure log, or a longer period allowed by the Ombudsman.

If you wish to request a review of my decision you may write to the Ombudsman at:
The ACT Ombudsman
GPO Box 442
CANBERRA ACT 2601
Via email: ombudsman@ombudsman.gov.au

ACT Civil and Administrative Tribunal (ACAT) review
Under section 84 of the FOI Act, if a decision is made under section 82(1) on an Ombudsman review, you may apply to the ACAT for review of the Ombudsman decision.

Further information may be obtained from the ACAT at:

ACT Civil and Administrative Tribunal
Level 4, 1 Moore Street
GPO Box 370
Canberra City ACT 2601
Telephone: (02) 6207 1740
www.acat.act.gov.au

If you have any queries concerning the directorate's processing of your request, or would like further information, please contact the directorate's FOI Coordinator on 6205 5408 or email tccs.foi@act.gov.au.

Yours sincerely

[redacted]

Cherie Hughes
Information Officer

7 November 2019

Bus Trips, Perimeters

All Dates	
Fiscal Quarter	2019-Q3
Fiscal Month	2019-Apr
Routes	
Route	056
	057
	058
	1
	7
	30
	31
	39
	200
	251
	252
	254
	255
	259
	712
	714
	930
	931
	936
	956
	958
	980
	411
	423
	431
	574
	596
	608
All Tickets	
Ticket Type	MyWay
	Paper Ticket

Stops All stops

Bus Trips, Definitions

A Passenger Trip is equivalent to a leg of a Passenger Journey. A Passenger Trip is recorded when a passenger Tags On or Transfers (on) with a MyWay card.

Paper tickets purchased and passenger counts recorded on the vehicle are also counted as representing a Passenger Trip.

Bus Trips, Aggregated Data

Date	Passenger Trips
01-Jan-2019	2,364
02-Jan-2019	7,553
03-Jan-2019	8,527
04-Jan-2019	8,849
05-Jan-2019	4,928
06-Jan-2019	3,519
07-Jan-2019	10,306
08-Jan-2019	10,184
09-Jan-2019	10,789
10-Jan-2019	10,850
11-Jan-2019	10,336
12-Jan-2019	4,105
13-Jan-2019	2,993
14-Jan-2019	11,692
15-Jan-2019	11,547
16-Jan-2019	11,710
17-Jan-2019	11,363
18-Jan-2019	11,225
19-Jan-2019	4,114
20-Jan-2019	3,030
21-Jan-2019	11,764
22-Jan-2019	12,709
23-Jan-2019	12,178
24-Jan-2019	12,186
25-Jan-2019	11,274
26-Jan-2019	3,884
27-Jan-2019	2,925
28-Jan-2019	2,886
29-Jan-2019	12,519
30-Jan-2019	12,806
31-Jan-2019	13,151
01-Feb-2019	12,954
02-Feb-2019	4
03-Feb-2019	3,291
04-Feb-2019	13,506
05-Feb-2019	14,864
06-Feb-2019	15,548
07-Feb-2019	15,607
08-Feb-2019	15,006
09-Feb-2019	4,885
10-Feb-2019	3,543
11-Feb-2019	15,817
12-Feb-2019	16,481
13-Feb-2019	16,318
14-Feb-2019	16,253
15-Feb-2019	16,046

Bus Trips, Aggregated Data

16-Feb-2019	7,135
17-Feb-2019	4,323
18-Feb-2019	16,252
19-Feb-2019	16,909
20-Feb-2019	16,830
21-Feb-2019	16,872
22-Feb-2019	16,619
23-Feb-2019	7,251
24-Feb-2019	4,859
25-Feb-2019	17,559
26-Feb-2019	18,388
27-Feb-2019	18,065
28-Feb-2019	18,169
01-Mar-2019	17,507
02-Mar-2019	5,601
03-Mar-2019	3,954
04-Mar-2019	17,380
05-Mar-2019	17,507
06-Mar-2019	17,847
07-Mar-2019	18,412
08-Mar-2019	17,530
09-Mar-2019	5,428
10-Mar-2019	4,202
11-Mar-2019	4,034
12-Mar-2019	18,059
13-Mar-2019	18,185
14-Mar-2019	18,048
15-Mar-2019	17,978
16-Mar-2019	6,575
17-Mar-2019	3,727
18-Mar-2019	17,332
19-Mar-2019	17,765
20-Mar-2019	17,944
21-Mar-2019	18,559
22-Mar-2019	17,555
23-Mar-2019	5,707
24-Mar-2019	3,931
25-Mar-2019	17,013
26-Mar-2019	18,283
27-Mar-2019	17,675
28-Mar-2019	18,158
29-Mar-2019	16,682
30-Mar-2019	4,991
31-Mar-2019	3,770
01-Apr-2019	17,106
02-Apr-2019	17,746
03-Apr-2019	17,698

Bus Trips, Aggregated Data

04-Apr-2019	18,134
05-Apr-2019	17,014
06-Apr-2019	5,363
07-Apr-2019	4,180
08-Apr-2019	16,687
09-Apr-2019	16,683
10-Apr-2019	16,628
11-Apr-2019	16,802
12-Apr-2019	16,170
13-Apr-2019	5,235
14-Apr-2019	3,899
15-Apr-2019	13,702
16-Apr-2019	14,069
17-Apr-2019	14,037
18-Apr-2019	13,759
19-Apr-2019	2,757
20-Apr-2019	4,802
21-Apr-2019	3,463
22-Apr-2019	6,420
23-Apr-2019	17,770
24-Apr-2019	18,989
25-Apr-2019	7,174
26-Apr-2019	18,140
27-Apr-2019	9,532
28-Apr-2019	8,145

Light Rail, Definitions

A Passenger Trip is equivalent to a leg of a Passenger Journey. A Passenger Trip is recorded when a passenger Tags On or Transfers (on) with a MyWay card.

Paper tickets purchased and passenger counts recorded on the vehicle are also counted as representing a Passenger Trip.

UNCLASSIFIED

Light Rail, Aggregated Data

Date	Passenger Trips
29-Apr-2019	14,969
30-Apr-2019	16,549
01-May-2019	17,248
02-May-2019	16,647
03-May-2019	16,274
04-May-2019	12,025
05-May-2019	8,880
06-May-2019	16,885
07-May-2019	17,826
08-May-2019	16,945
09-May-2019	17,347
10-May-2019	15,971
11-May-2019	10,512
12-May-2019	8,062
13-May-2019	16,538
14-May-2019	17,948
15-May-2019	18,217
16-May-2019	17,802
17-May-2019	18,936
18-May-2019	10,870
19-May-2019	8,241
20-May-2019	16,980
21-May-2019	17,766
22-May-2019	18,252
23-May-2019	18,033
24-May-2019	18,805
25-May-2019	11,226
26-May-2019	9,361
27-May-2019	5,192
28-May-2019	14,916
29-May-2019	14,119
30-May-2019	15,170
31-May-2019	15,300
01-Jul-2019	12,931
02-Jul-2019	13,822
03-Jul-2019	13,670
04-Jul-2019	13,675
05-Jul-2019	13,189
06-Jul-2019	6,682
07-Jul-2019	4,891
08-Jul-2019	11,943
09-Jul-2019	13,224
10-Jul-2019	12,690
11-Jul-2019	12,011
12-Jul-2019	11,580
13-Jul-2019	5,853

Light Rail, Aggregated Data

14-Jul-2019	4,012
15-Jul-2019	12,099
16-Jul-2019	13,003
17-Jul-2019	13,145
18-Jul-2019	13,433
19-Jul-2019	13,545
20-Jul-2019	7,305
21-Jul-2019	5,533
22-Jul-2019	14,910
23-Jul-2019	15,715
24-Jul-2019	15,491
25-Jul-2019	15,639
26-Jul-2019	15,438
27-Jul-2019	7,284
28-Jul-2019	5,207
29-Jul-2019	14,807
30-Jul-2019	16,123
31-Jul-2019	15,796
01-Aug-2019	16,051
02-Aug-2019	15,888
03-Aug-2019	7,891
04-Aug-2019	5,328
05-Aug-2019	15,164
06-Aug-2019	15,916
07-Aug-2019	15,475
08-Aug-2019	14,768
09-Aug-2019	13,468
10-Aug-2019	6,174
11-Aug-2019	4,592
12-Aug-2019	14,560
13-Aug-2019	15,798
14-Aug-2019	15,327
15-Aug-2019	15,735
16-Aug-2019	15,793
17-Aug-2019	7,278
18-Aug-2019	5,051
19-Aug-2019	14,621
20-Aug-2019	15,638
21-Aug-2019	15,521
22-Aug-2019	15,842
23-Aug-2019	15,762
24-Aug-2019	7,199
25-Aug-2019	5,109
26-Aug-2019	14,859
27-Aug-2019	15,461
28-Aug-2019	15,466
29-Aug-2019	15,551

Light Rail, Aggregated Data

30-Aug-2019	15,519
31-Aug-2019	7,728
01-Sep-2019	5,390
02-Sep-2019	14,183
03-Sep-2019	14,524
04-Sep-2019	14,547
05-Sep-2019	14,709
06-Sep-2019	14,102
07-Sep-2019	7,046
08-Sep-2019	5,585
09-Sep-2019	14,016
10-Sep-2019	14,826
11-Sep-2019	14,958
12-Sep-2019	14,914
13-Sep-2019	16,157
14-Sep-2019	8,221
15-Sep-2019	5,794
16-Sep-2019	14,900
17-Sep-2019	14,955
18-Sep-2019	16,044
19-Sep-2019	15,997
20-Sep-2019	17,758
21-Sep-2019	6,320
22-Sep-2019	6,029
23-Sep-2019	15,079
24-Sep-2019	16,172
25-Sep-2019	16,324
26-Sep-2019	15,266
27-Sep-2019	16,388
28-Sep-2019	7,794
29-Sep-2019	5,934
30-Sep-2019	14,353
Total	1,627,276